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A Publication of the Society of Economic Paleontologists and Mineralogists
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NOTICE

Articles submitted for publication in the *Journal of Sedimentary Petrology* should be original pages, typewritten double-spaced on 8½ by 11-inch white paper. A prefatory abstract is required for all papers, exclusive of short notes and discussions. The mechanical details of the manuscript should conform with usage in recent issues of the *Journal*, particularly in regard to capitalization and citation of references. Tables and illustrations should be separate from the text, and originals of illustrations are preferred. Detailed instructions and suggestions are given in the March, 1958 issue of the *Journal* (v. 28, p. 102–107).

Second-class mail privileges authorized at Menasha, Wisconsin.

Among papers to appear in forthcoming issues of the *Journal* are the following:

Two undescribed structures in a greywacke series. By Alan Wood and A. J. Smith

Description of a portable piston corer for use in shallow water. By Donald J. Reish and Keith E. Green

Comparison of phi percentage deviations. By William F. Tanner

Preliminary observations on chemical data from some British Upper Carboniferous shales. By John Trevor Greensmith

Clay mineral composition of Recent sediments from the Mississippi River Delta. By W. D. Johns and R. E. Grim

Micro-mechanisms of sedimentation in the epicontinental environment. By Albert Carozzi

Syngenetic chert in the Middle Ordovician Hardy Creek Limestone of southwest Virginia. By Leonard D. Harris

Differentiation of various Egyptian aeolian microenvironments by mechanical composition. By Stuart A. Harris

Displacement of microfossils. By Daniel J. Jones

Differentiation of beach, dune, and aeolian flat environments by size analysis, Mustang Island, Texas. By Curtis C. Mason and Robert L. Folk

Etching technique for use on thin sections of limestones. By Alan Lees

Rate of formation of a diagenetic calcareous concretion. By H. M. Pantin

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FIGS. 1–3, PLATE 1, MARCH, 1958

CYCLIC PATTERNS IN MECHANICALLY DEPOSITED PENNSYLVANIAN LIMESTONES OF NORTHEASTERN NEVADA

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Bedford, Massachusetts

ABSTRACT

Pennsylvanian sediments in northeast Nevada consist of limestone (80–90%) with smaller quantities of quartz sandstone, siltstone, and chert conglomerate. Outcrop patterns and details of lithology show cyclic alternations. Mechanically deposited limestone exceeds 25% of the total limestone, and includes bioclastic calcarenite and calcirudite and some oölite. Detrital quartz impurities are characteristic. Non-mechanical coquinoid limestones alternate with mechanical varieties. Characteristic nodular chert is secondary (diagenetic) and occurs in very cherty units alternating with non-cherty units. Fossils are not well preserved except where silicified.

Algal remains, fragmented fossils, detrital quartz, oölite, and numerous diastems indicate shallow water, frequent agitation, winnowing, and redeposition. Alternating with these conditions were periods of less intense stirring of accumulating sediment, producing cyclic patterns. Orogeny in the eugeosyncline produced lands which shed quartz and chert detritus eastward into the miogeosyncline. Presence of notable quartz sandstones and limestones in the eugeosyncline contradicts popular concepts of only impure "graywacke" sands in such provinces to the near exclusion of all other sediment types. Local upwarps and platforms within the miogeosyncline subsided less rapidly and furnished clastics to adjacent negative areas. The limestones and associated quartzose sandstones lithologically qualify as stable shelf deposits like typical sequences of the craton. The Nevada ones are much thicker however, indicating more rapid subsidence in a relatively unstable geosynclinal belt. While depositional environments in the two provinces were identical, tectonic environments differed considerably as evidenced by significantly thicker deposits, local angular unconformities and appreciable chert detritus in Nevada.

INTRODUCTION

Pennsylvanian rocks in eastern Nevada are predominantly limestone. Between Elko and Eureka (fig. 1) they comprise 3000 to 4000 feet of cherty limestone, quartz arenite, and siliceous conglomerate (Dott, 1955). In east-central Nevada, non-conglomeratic facies (Ely Limestone) are approximately 3000 feet thick. Three characteristics of the limestones are outstanding: their cyclic pattern, the importance of mechanically deposited limestone, and the abundance of nodular chert.

One is immediately impressed with the cyclic or rhythmic appearance of the Pennsylvanian throughout the Great Basin. The exact nature of the rhythmic pattern in Nevada is obscure, however, because the strata are so predominantly limestone. The purpose of this report is to discuss this important characteristic in greater detail than was possible in earlier papers. The sediment types, including nodular chert, are described and classified, and their origin is discussed from the standpoint of fluctuating sedimentation as related to paleoecology of the fossil faunas. Implications of the sedimentary lithologies to regional stratigraphic and tectonic classifications are also examined briefly.

[1] Geophysics Research Directorate, Air Force Cambridge Research Center; on military leave from Humble Oil and Refining Company. Manuscript received March 15, 1957.

SEDIMENT TYPES

Conglomerate.—Brown-weathering chert- and quartzite-pebble conglomerate is predominant in the Mississippian of central Nevada and locally in basal and Middle Pennsylvanian and Wolfcampian sediments.[2] Rounded chert pebbles and cob-

[2] Nolan, *et al* (1956) named two Permian? formations with conglomerate and concluded that the Garden Valley Formation at Tyrone Gap is so dissimilar to contemporaneous rocks around Eureka that the Roberts Mountain Thrust must separate it from the more easterly sequences. Extensive early Permian sediments in the north Diamond Range (Dott, 1955) are nearly identical with the type Garden Valley Formation 15 miles west. Facies variations readily explain minor differences; thus there seems no necessity for postulating such intense post-Permian thrusting between these areas. The writer believes that stratigraphic evidence favors a Mississippian age for the Roberts Mountain Thrust. E. R. Larson advises that pebbles in Permian conglomerate at Palmer Ranch north of Eureka are limestone rather than chert as erroneously reported by Dott (1955, p. 2273).

bles exceed rare meta-quartzite clasts approximately 4 to 1. Interbedded with the conglomerates are numerous beds of firmly cemented tan to brown-weathering sandstone (quartz-chert arenite, pl. 1, fig. 4). Though superficially resembling true quartzite, these rocks lack evidence in thin section of metamorphic strain or intergranular suturing. Grains consist of subangular to subround clear quartz and brownish microcrystalline chert. Stratification is almost entirely planar; cross-stratification and ripple mark are conspicuously absent. Also interbedded with the conglomerate are thin units of gray, fragmental limestone containing a variety of bioclastic debris. The conglomerates as well as associated sediments are considered marine deposits.

Quartz siltstone and sandstone.—In addition to occurring as interbeds in predominantly conglomeratic units, variable amounts of quartz silt and sand are associated with the limestone everywhere. Tan, platy, calcareous quartz siltstone interbeds are very common, particularly in the Upper Pennsylvanian and Wolfcampian sediments. Scattered quartz grains also contaminate much of the limestone itself. The sandstones are classed as quartz-chert arenites, for they consist of approximately 60 percent quartz, 30 percent chert, subordinate siliceous and carbonate cement, and very rare accessory minerals. Authigenic enlargement of quartz grains in the sandstones and limestones is common (pl. 1, fig. 3).

Limestone.—The most important Pennsylvanian rock type in the region is gray limestone with variable quantities of nodular chert. Dolomite is virtually totally lacking. Several important limestone varieties are present, and although they intergrade, some distinction is essential for clear interpretation of their origins. Understanding of carbonate rocks has been retarded by superficial examination and lumping under all-inclusive terms. Carbonates are unique in bridging the gaps between mechanical, chemical, and biological processes which inevitably renders them difficult to understand and necessitates special techniques for their study and classification.

Because of the confused state of limestone classification, Rodgers (1954) attempted a very useful compilation of usage of terminol-

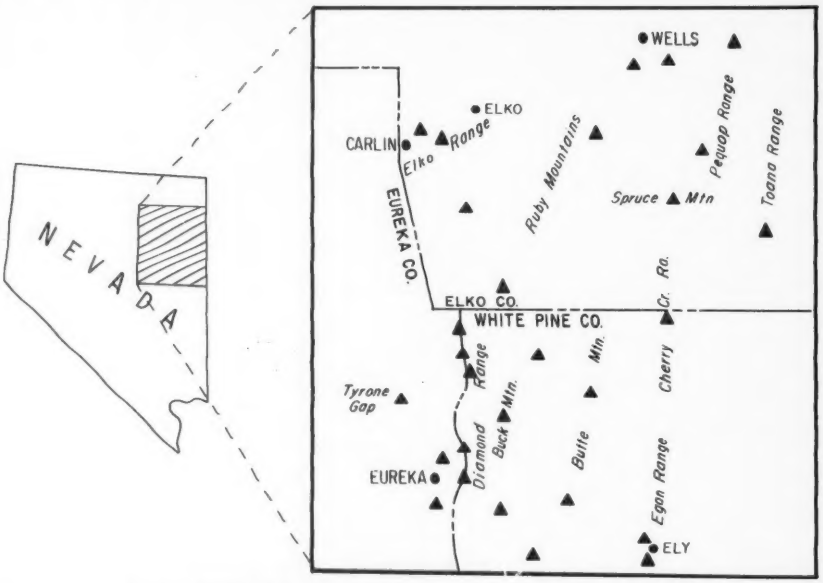

FIG. 1.—Index map of northeastern Nevada. Triangles indicate principal stratigraphic sections studied.

TABLE 1.—*Relative abundance of sediment types*

	Total section considered	Siliceous clastics*	All limestone	Calcarenite (percent of total limestone)†
Elko area	8346′	17%	83%	20%
Northern Diamond Range	5091′	4%	96%	25%

* Conglomerate, sandstone, siltstone.
† Coarse-textured limestone with positive evidence of mechanical action; minimum percent.

ogy, and in general the writer follows his recommendations. Grabau's classification (1904) is very comprehensive, but is not widely used. His scheme was employed with modifications in measuring stratigraphic sections for the present work, but more familiar terms are also used for general discussions according to the following scheme:

MECHANICAL—particles brought to site of deposition by currents or waves:
Fragmental or *Clastic*—pieces of something pre-existing; shells, rocks:
Detrital—derived from pre-existing rocks (after Lyell, 1840)
Bioclastic or skeletal—derived from contemporaneously formed biological material:
crinoidal calcarenite (encrinite)
fossil hash calcarenite (microcoquinite)
coquinite
Non-Fragmental—newly precipitated particles subject to mechanical action; aragonite needles, oöliths, etc.
NON-MECHANICAL—not disturbed from position of origin (organic reefs, undisturbed coquinites, coquinoid limestone, etc.)

The term "organic limestone" will be avoided, for it could mean: rich in carbon compounds, rich in skeletal remains, or precipitated as byproducts of organisms such as bacteria.

The quantitative importance of mechanically deposited limestone has become apparent in recent years, and evaluation of such limestones has particular import to paleoecological considerations. The Pennsylvanian of northeast Nevada provides abundant evidence for this conclusion, since more than 25 percent of the limestones bear testimony to at least some mechanical action (table 1). Such action varied in degree only. Clastic-textured limestone varieties with mixed and fragmented fossil hash, quartz sand, and scattered chert pebbles represent one extreme whereas fine-grained limestone with fewer fossils and very rare quartz silt grains represent another. These deposits are properly regarded as intimate mixtures of four end members: carbonate fragments, quartz and chert fragments, and chemically precipitated (diagenetic) chert. Such complex mixtures obviously are difficult subjects for quantitative lithofacies studies if important characters are not to be masked.

Several recurring types of mechanical limestone were distinguished. Bioclastic varieties include what are here termed *crinoidal calcarenite*, *fossil hash calcarenite*, and *calcirudite*. Rare *oölite* is associated. These types (pl. 1, figs. 3, 5–8) generally contain significant quantities of detrital quartz impurity, and even if other criteria were lacking, this alone would indicate a mechanical origin for such deposits. The fossil material in the fragmental limestones shows all degrees of breakage and abrasion; rare examples possess remarkably rounded fragments (pl. 1, fig. 5). Brachiopod, Bryozoan, fusulinal and coralline *coquinites*, thin units composed almost wholly of fossils, are commonly associated with the calcarenites (pl. 1, fig. 2). *Diastems*, minor breaks in deposition due to submarine scour, are characteristic of these deposits, and constitute further evidence of mechanical action. They are recognized by irregular "disconformable" or scoured contacts (pl. I, fig. 1) and small concentrations of chert pebbles, coarse fossil hash and quartz sand which grade up to finer, more pure limestone.

Other limestone types such as *coquinoid* and *coralline limestone* are practically non-mechanical and alternate more or less regularly with the truly mechanical varieties. No reef limestone was observed, but closely crowded *Chaetetes* colonies occur in a thin zone that is persistent over a large region (Dott, 1955).

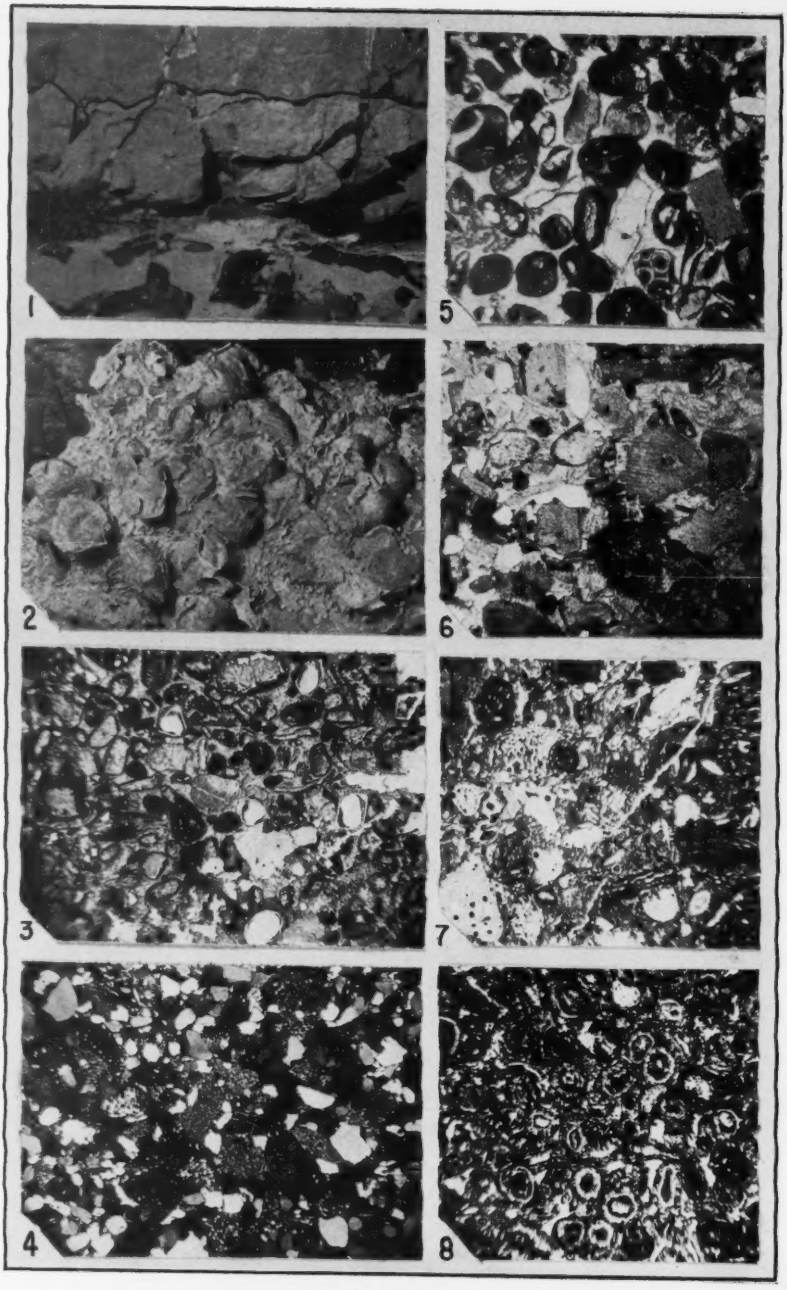

PLATE 1

It is significant that, although conglomerate and quartz sand and silt are common associates of the limestones, there is a conspicuous dearth of clay shale. Pettijohn (1949, p. 205) considers this condition characteristic of mechanical limestone suites, and infers that clay-size material was bypassed elsewhere. It is probable that in some cases little or no clay size material was ever supplied to depositional areas, for none of the Pennsylvanian has appreciable shale throughout the central Great Basin.

Chert.—Most of the limestone, particularly in the Lower Pennsylvanian, contains at least small quantities of nodular chert, and many units are more than 30 percent chert. Banding and zoning in the chert is rare, but some nodules have a silica shell surrounding a limestone core. Distinctive concentric banding encountered in east-central and southern Nevada and western Utah represent either replaced algal remains or contraction spheroids resulting from rhythmic shrinkage during dehydration of silica gel or opal to chalcedony and quartz (Taliaferro, 1934). Most of the chert is not pure silica, but contains fine disseminated calcite. It weathers dark gray or brownish, but very impure phases weather light gray and have finely porous exteriors due to leaching of carbonate.

The chert originated through metasomatic replacement of an originally calcareous sediment. Thin sections reveal fossil material in textural patterns identical with those of the enclosing limestone, but showing variable replacement by chalcedonic silica and fine quartz. Matrix is finer microcrystalline quartz and chalcedony containing scattered carbonate rhombs and disseminated organic matter. Replacement of fossils varied in degree according to size and type of shell structure, the large impervious shells commonly showing only incipient replacement at their margins. Completely unreplaced material is common, too, particularly massive fragments such as crinoid columnals. In the limestone adjacent to nodules isolated fossils have been completely chertified in an apparently random fashion.

Though the chert is clearly secondary, sources of the silica are conjectural. If originally siliceous animal remains supplied it, then solution has erased their identity. Older Paleozoic chert, quartzite, and siliceous shales extensively exposed in western Nevada during the Pennsylvanian probably supplied much silica of inorganic origin. Dissolved or colloidal silica disseminated in accumulating calcareous oozes was gradually concentrated by ionic and Van der Waals forces during diagenesis. Maximum mobility and migration would occur during compaction when fluids were being squeezed through and out of the sediments. Hatch, *et al.* (1938, p. 212) concluded that chertification occurred after diagenesis began, but when matrix was still unrecrystallized and in a much more reactive condition than crystalline inclusions such as crinoid fragments or dolomite crystals. Newell, *et al.* (1953) also presented convincing arguments for diagenetic origin of chert. Uniform vertical spacing of nodules and stringers suggests fairly

PLATE 1

FIG. 1.—Diastem between fine cherty limestone below and coarse, quartz-sandy calcarenite above the irregular scour surface. Middle Moleen Formation, Grindstone Mountain, Elko Range. (Area of view approximately 2 feet high.)

FIG. 2.—Acid-etched coquinite with little-damaged *Cleiothyridina* and *Composita*. Lower Tomera Formation, Elko Range. (×¼)

FIG. 3.—Authigenic euhedral quartz grain enlargements in typical quartz-sandy calcarenite; includes scattered, transported microfossils ("spergenite" of Pettijohn). Middle Moleen Formation (*Paramillerella* zone), Grindstone Mountain. (×12)

FIG. 4.—Quartz-chert arenite typically associated with chert-pebble conglomerates. Quartz is clear, chert mottled. Upper Tonka Formation, Grindstone Mountain. (×12) (crossed nicols)

FIG. 5.—Pure calcarenite with exceptionally rounded grains of fossil debris, predominantly of Bryozoa and crinoids. Middle Moleen Formation, northern Diamond Range. (×12)

FIG. 6.—Crinoidal calcarenite with minor quartz grains; the most abundant mechanical limestone variety, composed almost entirely of echinoderm debris. Upper Moleen Formation, northern Diamond Range. (×12)

FIG. 7.—Fossil hash calcarenite: a heterogeneous mixture of badly broken fragments of several fossil types (fusulinids, crinoids, productid spines, Bryozoa, etc.). Upper Tomera Formation (*Fusulina* zone). (×12)

FIG. 8.—Oölite; non-fragmental mechanical limestone variety indicative of strongly agitated water. Middle Ely Limestone, Ward Mountain, Ely, Nevada. (×12)

uniform original dissemination of silica with subsequent concentration into individual stringers from above and below each (see also Chilingar, 1956).

Krumbein and Garrels (1952) believe that pH and oxidation-reduction potential (Eh) are of fundamental importance in formation of chemical sediments. Burial of sediment excludes oxygen, and attack of organic matter by anaerobic bacteria generates hydrogen sulfide. These factors produce an abrupt change to reducing conditions (−Eh) which makes mineral associations which were stable at the depositional interface (with +Eh) become unstable upon burial. Extensive replacements, including chert formation, between minerals of lower and higher oxidation states would occur, particularly during early compaction. Chilingar (1956) finds percentage of chert proportional to Ca/Mg ratio and precipitation of silica favored by decreasing pH (i.e. acidity). Primary dolomite is presumably favored by high pH and elevated temperature. If this be true, the very cherty nature of the Nevada Pennsylvanian limestones is consistent with their non-dolomitic character.

Cyclic development is suggested by alternations of conspicuously banded, cherty units with virtually chert-free ones. However, relation to limestone lithology, stratigraphic position, and the thickness of cherty units appears to be random; therefore, the writer believes that variable quantities of silica and varying abundance of organic compounds buried in the sediments controlled subsequent distribution of chert. Detailed statistical analysis of chert distribution might reveal a more systematic pattern than was apparent to the writer.

Fossil Silicification.—Fossil preservation is poor to moderate. Few forms weather out of the rock intact because they are imbedded in calcium carbonate matrix as resistant as the shells themselves. Some units which have undergone sufficient fossil silicification yield good faunules by acid etching, but selectivity of silicification causes them to be rather unvaried. Fossils are commonly silicified on outcrop surfaces only, and some weathered rock surfaces themselves have fine siliceous crusts. Such surficial silica probably was brought to outcrop surfaces by capillary action, analogous to case-hardening, and constitutes a relatively recent weathering phenomenon.

Fossils are silicified well below outcrop surfaces in many cases, and such material yields excellently preserved specimens by acid etching. Thick shells were not generally replaced completely, but only along their interior and exterior surfaces. The calcite between etches away leaving delicate, hollow, silicified crusts. The time of silicification of this sort of material is uncertain, although Newell, *et al.* (1953) consider all fossil silification to occur early.

Fossil types vary greatly in susceptibility to silicification. Punctate brachiopods and corals were most easily and consistently attacked. Spiriferids and productids were commonly affected as were fenestrate Bryozoa (see also Newell, *et al.*). Permeability and exposed surface area of skeletal material seem the most important factors determining ease of replacement; size is of little importance. Although massive echinoderm fragments are the least replaced forms in chert nodules (contrary to an opinion quoted by Chilingar, 1956), they are paradoxically perfectly silicified on the surfaces of some calcarenites. Foraminifera were almost completely immune to silicification.

Quantity of silica available and relative abundance of different fossil materials at a given time and place apparently controlled silicification. Thus crinoid fragments, among the last affected, were replaced together with associated matrix in chert nodules only where sufficient silica and time were available. Replacement of fossils only in a calcite matrix presumably represents later introduction of silica when the matrix was consolidated and less susceptible to replacement than fossil material, the interface between fossil and matrix providing access for solutions. Early versus later introduction of silica relative to time of consolidation of matrix may account for unreplaced fossils in chert (i.e. early introduction) in contrast to silicified fossils in unreplaced matrix (later introduction).

Stratification.—Pennsylvanian and Wolfcampian limestones throughout the central Great Basin crop out as conspicuous alternating low cliffs and covered intervals (fig. 2). In the cliffs, distinct stratification planes vary from 2 to more than 4 feet apart with less distinct, wavy stratification between in many cases. Quartz sandy and conglomer-

FIG. 2.—Characteristic outcrop pattern of alternating low cliffs and covered intervals, Moleen Formation (Lower Pennsylvanian), Grindstone Mountain near Elko, Nevada; typical of Pennsylvanian and Wolfcampian throughout central Great Basin.

atic Upper Pennsylvanian limestones near Elko possess conspicuous small-scale cross-stratification (Dott, 1955). Poorly exposed intervals beween cliffs contain less resistant, thinly stratified and slightly nodular limestone or silty limestone. The uniformity of covered intervals is almost as important a characteristic as the nature of stratification in the outcrops.

Some numerical data were compiled (table 2) following the suggestion of Kelley (1956) that subjective, qualitative terms generally applied to stratification have little meaning save to their originator. Seven representative stratigraphic sections of the Lower Pennsylvanian Moleen Formation in three principal areas studied by the writer were chosen as examples. The sections used for comparison are as similar as possible in degree of exposure and quality of measurement, although they leave much to be desired for statistical treatment. Two intervals of 500 and 1000 feet respectively were analyzed for contrast.

The stratification index (Kelley, 1956) for different sections could be particularly instructive in regional studies of cyclic sediments. Although the results obtained are approximations only, a fair degree of consistency of stratification index and number of covered intervals is apparent, suggesting fairly uniform conditions over extensive areas. The slightly higher index near Elko, suggests correlation with greater quantities of siliceous clastic material associated with the limestones of that area, the greater degree of beddedness being directly related to more numerous vertical lithologic variations.

Typical widely correlative cyclothems could not be detected. This is in contrast to certain areas with Pennsylvanian rocks such as the eastern interior states. The cyclic repetition in Nevada is much more subtle, occurs on a smaller scale and is more variable laterally than in true cyclothems.

PALEOECOLOGY AND CYCLIC SEDIMENTATION

Several consistent fossil associations of presumed ecologic significance were noted in the course of the work. Fusulinids are rather exclusive, but do occur with corals, particularly *Syringopora;* they are very rare with Bryozoa. Brachiopods occur with practically all other fossils, though productids are most commonly associated with Bryozoa. Both productids and Bryozoa are most abundant in the finer limestones. They apparently preferred relatively quiet, muddy bottoms as testified by their matrix and the preservation of delicate spines. Encrusting Bryozoa are fairly common in these assemblages, also. Spiriferids, *Cleiothyridina* and other brachiopods are most common in

TABLE 2.—*Stratification data for Moleen Formation (Lower Pennsylvanian)*

	Lower Moleen Formation (Ely Group)							Lower and Middle Moleen Formation			
	Elko Range		Diamond Ra.		Buck Mt.	Butte Mtns.		Elko Ra.	Diamond Ra.		Butte Mtns.
	I	II	III	IV	V	VI	VII	IIa	IIIa	IVa	VIIa
Total interval (feet)	500	500	500	500	500	500	500	1000	1000	1000	1000
Percent covered	22	39	26	37	23	34	16	37	24	27	20
Number covered intervals	15	16	8	8	15	4?	17	31	17	15	24
Number exposed beds	51	45	22	24	31	27	43	79	61	63	68
Total exposed thickness	391	307	371	315	384	332	423	628	758	735	804
Stratification index*	13.0	14.7	5.9	7.6	8.1	8.1	10.2	12.6	8.1	8.6	8.5

* Stratification index $= \frac{\text{Number beds} \times 100}{\text{Thickness}}$ (after Kelley, 1956).

coarser limestones and quartz arenites, and commonly formed rich coquinite beds. These organisms probably flourished on harder bottoms with moderate currents as suggested by their clastic matrix as well as by numerous disarticulated and abraded shells. Crinoids must have been very abundant and probably favored somewhat agitated water since their plates were almost entirely disarticulated, transported and deposited as crinoidal calcarenites.

All degrees of posthumous mixing of organisms can be recognized in the faunas. One of the least disturbed assemblages is the *Chaetetes-Profusulinella* zone in the upper Moleen Formation. Most of the *Chaetetes* coral colonies are in original growth positions and commonly have encrustations of other corals or Bryozoa. In associated fusulinal beds all sizes of different Foraminifera, including many juveniles, are abundant. All evidence indicates that conditions were exceptionally uniform and calm over wide areas during development of this zone. Other assemblages which were extensively disturbed and mixed are represented by fossil hash calcarenites in which fossil material is badly broken, abraded and more or less sorted with few if any juvenile forms present. Such rocks generally contain some quartz silt or sand and scattered oöliths. Crinoidal calcarenites are most typical and may contain scattered fusulinids which were transported and mixed with crinoid debris. Certain fusulinid-rich deposits, particularly in the Upper Pennsylvanian and Wolfcampian, contain assemblages which were transported and sorted, more or less crushed, recrystallized and redeposited in a calcareous quartz silt or sand. Fusulinid tests must have been somewhat buoyant (or of low specific gravity) because they commonly occur in silt and sand beds of much finer grain size than the tests.

The gradations in degree of transport and mixing can not be confidently differentiated in most cases.[3] For example, some brachiopod coquinites appear to have been transported while others show no evidence of breakage or abrasion. Furthermore, different fossils have differing susceptibility to damage. Echinoderm plates and spines, for instance, are joined in life only by protoplasm, so they fall apart readily upon death unless buried on very quiet bottoms, whereas thick-shelled spiriferids could withstand considerably more agitation without appreciable damage.

The writer concludes that these Pennsylvanian organisms lived in a relatively shallow sea which was subjected to considerable wave and current action, at least periodically. That the water was rather clear seems probable, partly because of paucity

[3] Menard and Boucot (1951), Boucot (1953) and Newell, *et al.* (1953) studied transport and mixing of bivalves by experiments and statistical analysis of modern and fossil assemblages. Müller (1950) proposed an elaborate terminology for shell and shell-fragment limestones based upon minor variations in degree of disturbance. The Germans carry such refinements to extremes in studies called Biostratonomy, i.e. the relations of fossils to each other and to their containing sediments.

of argillaceous material. Elias (1937) argued that fusulinids preferred depths of 160 to 180 feet, whereas brachiopod-Byrozoan-coral assemblages preferred 75 to 160 feet of water by analogy with similar modern organisms. Such absolute depth figures are suspect, but relative depths of different deposits can sometimes be inferred. There is no evidence indicating very great depths. Rare, presumably benthonic algal material and algal? spheres in *Profusulinella* beds and others suggest for these deposits clear water and depths not exceeding 300 feet, the lower limit of photosynthesis in sea water according to Sverdrup, *et al.* (1942; pp. 774–82). Encrusting algae occur in the Mississippian near Eureka, also. For the fusulinids, Nevada evidence supports Thompson's (1948, p. 7) conclusion that they had narrow tolerances and were restricted to non-brackish, offshore, open-water environments. Presumably they lived at relatively greater depths than most of the other faunal elements.

As suggested by Wanless and Paterson (1951), relation of fossils and containing deposits to some datum such as wave base is more important and objective than exact depth figures. However, even this interpretation is fraught with deceptions and depends largely upon evidence of degree of agitation of sediments and fossils. The question arises as to whether deep water currents or shallow waves have caused observed effects of agitation. Probably most of the fusulinal, brachiopod Bryozoa, and some coralline assemblages studied lived in quieter, possibly deeper, water. Such assemblages, where undisturbed, occur in predominantly fine, relatively thicker-stratified, coquinoid limestones. Increased wave or current action, and possibly shallower depths, must have existed periodically at which times thinner-stratified calcarenites and brachiopod coquinites accumulated (fig. 3). Many of the latter apparently represent lowering of wave base to rework slightly earlier deposits, concentrating shells as residual intraformational lag "conglomerates" by winnowing out of the finer matrix and small fossils. In this manner, moderately fossiliferous muds were transformed into much thinner, fossil-rich coquinites and calcarenites. Current and periodic storm-wave agitation of bottoms, possibly at depths of several hundred feet, is testified by extensive breakage, abrasion, winnowing and sorting of fragments, rolling over of corals from growth positions, associated detrital quartz and chert, rare oölite, diastems, and some cross-stratification. The curved nature of many horn corals as well as the cuneate (oval) cross-section of some has been interpreted by Easton (1951) as adaptations to currents. The numerous diastems produced by submarine scour (fig. 3) probably represent more actual elapsed geologic time than do the rocks which are preserved, and the scour and winnowing doubtless caused considerable reduction in thickness of accumulating sediments (Frizzell and Anderson, 1950; Larson, 1950). The environment envisioned is essentially that which Rich (1951) termed an unda environment.

Alternations of agitated and quiet bottom conditions produced the cyclic appearance of the Pennsylvanian thicker- and thinner-stratified limestones (fig. 3). Wanless and Paterson (1951) studied more pronounced cycles in Pennsylvanian limestone, shale, and sandstone in adjacent southwestern states, and Cline (1954) discussed cyclic Upper Pennsylvanian fusulinid and algal limestones in New Mexico. In both cases lateral facies changes occur which are analogous to vertical alternations of lithology in the same strata, and the authors consider that changes of water depth and vigor of bottom agitation have been the principal controlling factors, as is here postulated for Nevada. Cyclic deposition in the Mid-Continent Pennsylvanian is, of course, well known.

DEPOSITIONAL AND TECTONIC ENVIRONMENTS

Facies and overlap relations in central Nevada indicate westerly sources, that is, from the volcanic (eugeosynclinal) portion of the Cordilleran geosyncline, for most of the terrigenous chert, quartzite, and quartz detritus. In western Nevada there is much pre-Pennsylvanian chert interbedded with mudstone or shale. There are also beds of rather pure, light gray to white featureless quartzite in that region which presumably were derived originally from the east. The chert and quarzite were exposed to erosion by the Mississippian Antler Orogeny, and

large quantities were thence transported back eastward into the non-volcanic belt (miogeosyncline) as pebbles, sand and silt which contaminated the limestones accumulating there. These clastics therefore now represent at least second cycle sediments. Some quartz silt came from the positive elements within the miogeosyncline itself and

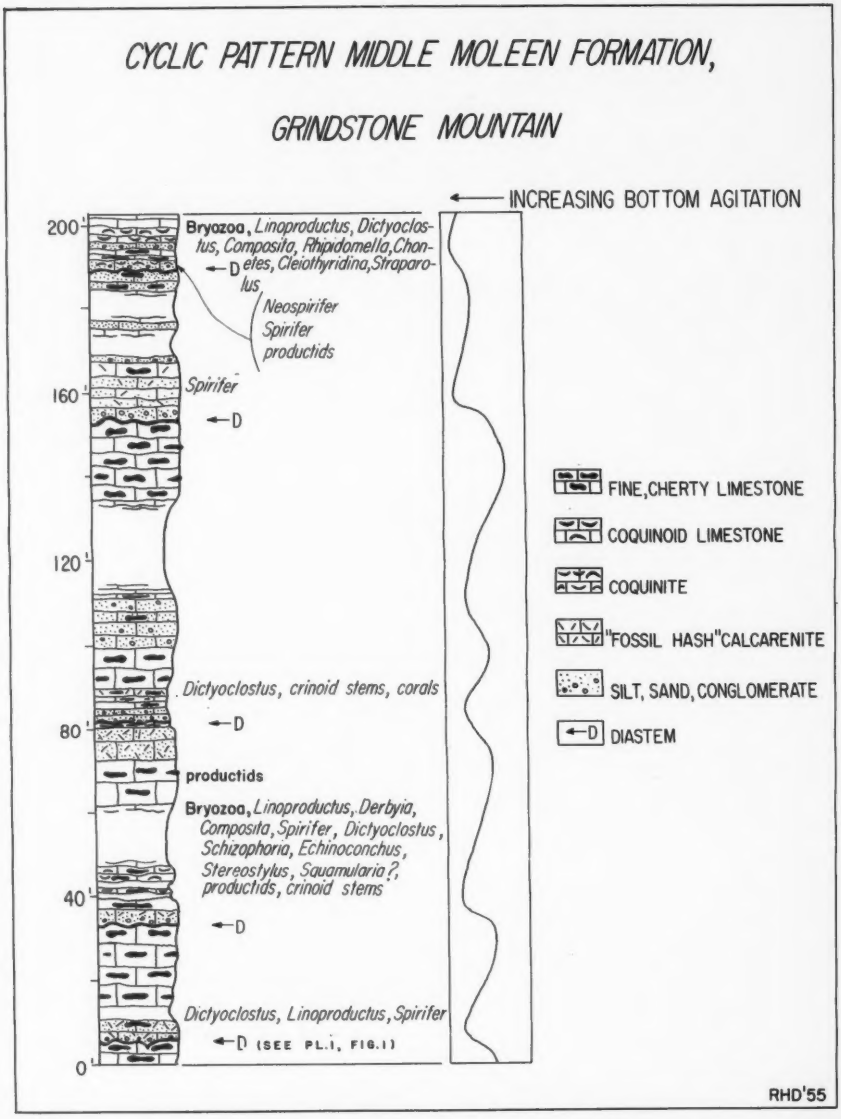

FIG. 3.—Cyclic pattern in Lower Pennsylvanian near Elko, Nevada.

presumably from the craton far to the east. The geosyncline did not subside uniformly, but was differentiated into basin, platform, and positive elements whose positions shifted through time.

Derivation of much pure quartzite and quartz from the west would be surprising according to popular petrographic generalizations which hold that virtually all eugeosynclinal sandstones are poorly sorted, clay-rich, quartz-poor "graywacke" types. There is even a tendency to restrict the term geosynclinal to thick accumulations of such sandstones and associated mudstone and chert, thus excluding equally thick sequences predominating in other rock types (such as eastern Nevada and western Utah). Such classification is too restrictive, since all sediment types are represented in the different stratigraphic-tectonic provinces, although in varying proportions (Kay, 1951, pp. 70–71, 88–90). In addition to the surprising number of rather pure quartzites in the western Cordillera, there also are thick and extensive limestones, particularly in northern California. Because the distribution of sediment types is statistical only, the abundance of volcanic rocks associated with sediments remains the most fundamental and objective peculiarity of a eugeosynclinal province.

The Pennsylvanian limestones of northeast Nevada possess virtually all the necessary requirements for classification as stable shelf deposits by virtue of the quartzose sand, fragmental limestones, numerous coquinites, moderately abundant fossils, and evidence of widespread mechanical deposition with development of many diastems (Krumbein and Sloss, 1951). In lithology these deposits almost exactly duplicate typical limestone suites of the stable interior (cratonal) region of the continent, indicating identical depositional environments for long times (i.e. shallow, agitated, "epicontinental" seas with much limestone accumulation). The tectonic environments of the two regions differed, however, for the Nevada deposits lie in a linear geosynclinal belt containing deposits of much greater thickness, indicating more rapid accumulation and subsidence even though there was no essential difference in depth of water or in bottom conditions. The thickness implies relative instability which is well shown by comparison of rates of accumulation, a close measure of subsidence rate since depth of water did not vary greatly. Considering 40 million years to be the approximate span of Pennsylvanian time (Holmes, 1947), an overall rate of 100 feet of sediment per one million years is obtained for northeast Nevada (4000 feet total Pennsylvanian rocks) and 400 feet per million years for the adjacent Oquirrh Basin of northern Utah (16,200 feet total; Thompson, *et. al*, 1950). These two rates illustrate the variation of subsidence within the miogeosyncline, further emphasized by the fact that four-fifths of the phenomenal Oquirrh Basin subsidence occurred during but one geologic period. Rates of sedimentation for contemporaneous stable areas of the craton differ sharply from those of the geosyncline, for example 7 feet per million years in the Grand Canyon area (280 feet total; McNair, 1951) and 20 feet per million years in southeastern Wyoming (800 feet total; Agatston, 1954). Several Pennsylvanian cratonal basins, of course, had rates comparable to northeast Nevada.

Krumbein and Sloss (1951, p. 336) point out that miogeosynclines are transitional in structure, lithology, and sedimentary thickness between eugeosynclines and cratons. In the present case, "stable shelf" describes a common depositional environment for the miogeosyncline and parts of the craton because of their close similarity of lithology. The Nevada deposits are distinguished only by greater thickness and an abundance of chert detritus. Westwardly increasing clastic chert and quartz together with angular unconformities reflect transition to more intense tectonism in the eugeosyncline.

ACKNOWLEDGEMENTS

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REFERENCES

AGATSTON, R. S., 1954, Pennsylvanian and Lower Permian of northern Wyoming: Am. Assoc. Petroleum Geologists Bull., v. 38, p. 508–83.

BOUCOT, A. J., 1953, Life and death assemblages among fossils: Am. Jour. Sci., v. 253, p. 25–40.

CHILINGAR, G. V., 1956, Distribution and abundance of chert and flint as related to Ca/Mg ratio of limestones: Geol. Soc. America Bull., v. 67, p. 1559–61.

CLINE, L. M., 1954, Relationships of invertebrate organisms in Pennsylvanian strata: Jour. Sedimentary Petrology, v. 24, p. 136.

DOTT, R. H., JR., 1955, Pennsylvanian stratigraphy of Elko and northern Diamond Ranges, northeastern Nevada: Am. Assoc. Petroleum Geologists Bull., v. 39, p. 2211–2305.

EASTON, W. H., 1951, Mississippian cuneate corals: Jour. Paleontology, v. 25, p. 380–404.

ELIAS, M. K., 1937, Depth of deposition of Big Blue Series, Kansas: Geol. Soc. America Bull., v. 48, p. 403–32.

FRIZZELL, D. L., AND ANDERSON, I. J., 1950, Diastems in Pecan Gap Chalk, Travis County, Texas: Jour. Sedimentary Petrology, v. 20, p. 55–59.

GRABAU, A. W., 1904, On Classification of sedimentary rocks: Am. Geol., v. 33, p. 228–47.

HATCH, F. H., RASTALL, R. H., AND BLACK, M., 1938, Petrology of the sedimentary rocks, 3d Ed., Murby, London, 383 p.

HOLMES, A., 1947, The construction of a geologic time scale: Geol. Soc. Glasgow, Trans., v. 21, pt. 1, p. 117–52.

KAY, M., 1951, North American geosynclines: Geol. Soc. America Memoir 48, p. 143.

KELLEY, V. C., 1956, Thickness of strata: Jour. Sedimentary Petrology, v. 26, p. 289–300.

KRUMBEIN, W. C., AND SLOSS, L. L., 1951, Stratigraphy and sedimentation, W. H. Freeman, Co., San Francisco, 497 p.

KRUMBEIN, W. C., AND GARRELS, R. W., 1952, Origin and classification of chemical sediments in terms of pH and oxidation-reduction potentials: Jour. Geology, v. 60, p. 1–33.

LARSON, E. R., 1950, Ordovician diastems in Missouri: Jour. Sedimentary Petrology, v. 20, p. 63–64.

LYELL, CHARLES, 1840, Principles of Geology. 6th ed., John Murray, London. 834 p.

MCNAIR, A. H., 1951, Paleozoic stratigraphy of part of northwestern Arizona: Am. Assoc. Petroleum Geologists Bull., v. 35, p. 503–41.

MENARD, H. W., AND BOUCOT, A. J., 1951, Experiments on the movement of shells by water: Am. Jour. Sci., v. 249, p. 131–51.

MÜLLER, A. H., 1950, Stratonomische untersuchungen im oberen Muschelkalk des Thüringer beckens: Geologica, Berlin, No. 4, 74 p.

NEWELL, N. D., ET. AL, 1953, Permian reef complex of Guadalupe Mountains region, Texas and New Mexico, W. H. Freeman, San Francisco, 236 p.

NOLAN, T. B., MERRIAM, C. W., AND WILLIAMS, J. S., 1956, The stratigraphic section in the vicinity of Eureka, Nevada: U. S. Geol. Survey Prof. Paper 276, 77 p.

PETTIJOHN, F. J., 1949, Sedimentary rocks, Harper brothers, New York, 526 p.

RICH, J. L., 1951, Three critical environments of deposition and criteria for recognition of rocks deposited on each of them: Geol. Soc. America Bull., v. 62, p. 1–20.

ROBERTS, R. J., 1951, Geology of Antler Peak quadrangle, Nevada: U. S. Geol. Survey Geol. Quad. Map 10.

RODGERS, J., 1954, Terminology of limestone and related rocks: Jour. Sedimentary Petrology, v. 24, p. 225–34.

SVERDRUP, H. U., JOHNSON, M. W., AND FLEMING, R. H., 1942, The Oceans. Prentice-Hall, New York, 1060 p.

TALIAFERRO, N. L., 1934, Contraction phenomena in cherts: Geol. Soc. America Bull., v. 45, p. 189–232.

THOMPSON, M. L., 1948, Studies of American fusulinids: Kansas Univ. Paleon. Contributions Protozoa, Article I. 184 p.

THOMPSON, M. L., VERVILLE, G. J., AND BISSELL, H. J., 1950, Pennsylvanian fusulinids of south-central Wasatch Mountains, Utah: Jour. Paleontology, v. 24, p. 430–65.

WANLESS, H. R., AND PATERSON, J., 1951, Cyclic sedimentation in marine Pennsylvanian of southwest U. S.: Extrait de Compte Rendu, Troisieme Congres de Stratigraphie et Geologie du Carbonifere, Heerlen, p. 655–64.

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FIGS. 1–8, MARCH, 1958

PETROGRAPHY AND POROSITY OF THE COW RUN SAND, ST. MARYS, WEST VIRGINIA[1]

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ABSTRACT

The petrographic characteristics of some Cow Run sandstones from four wells at St. Marys, West Virginia, are described and the relationship between petrography and porosity (and logarithm of the permeability) are evaluated by multiple regression approach.

It is shown that carbonate cement, when it exceeds 5 percent by weight, controls the porosity. When less than 5 percent of carbonate occurs the grain size, size-sorting, quartz, and silica cement are the main factors controlling the porosity in these oil sands.

INTRODUCTION

The definition of a specimen of sandstone in terms of its petrographic properties may be formally represented as

$$P = f(m, s, sh, o, p) \qquad (1)$$

(Griffiths, 1952a, 1952b) where P is some defining index expressed as a function (f) of the mineral composition (m), grain size (s), grain shape (sh) grain orientation (o), and grain packing (p). In reservoir engineering studies it is convenient to characterize the reservoir rock in terms of porosity, permeability, relative saturation, etc.; to understand the relationship between these reservoir characteristics and the controlling factors, the petrographic properties, the characteristic of interest may be substituted for (P) and the relationship evaluated in terms of some multiple regression equation.

In statistical notation, when using multiple regression procedure, P, the reservoir property, represents the dependent variable Y, and the independent variables, the petrographic characteristics, may be designated as $X_1, X_2, \cdots, X_n$. Equation (1) becomes:

$$Y = f(X_1, X_2, X_3, \cdots, X_n) \qquad (2)$$

Actual numerical values may then be substituted in equation (2), and the relationship between reservoir property and petrographic variables may be quantitatively evaluated.

Porosity is a suitable dependent property (Y) which may be related to petrography, and some understanding of the important controlling factors may thus be obtained. In many oil sands porosity is related to permeability and the relationship is exponential. In such cases, when permeability is plotted on a logarithmic scale and porosity on an arithmetic scale, a linear relationship emerges; the porosity and permeability of the Cow Run Sand is a typical example (fig. 1).[2] As a first approximation then, any relationship between porosity and petrography will also hold for the logarithms of the permeability. These relationships are not exact as can be seen from the scatter around the trend line of figure 1; in particular, the relationship between porosity and permeability breaks down in the range 0–10 percent porosity and less than 2 millidarcies permeability; in the Cow Run Sand it may be assumed that this is likely to be the range of least interest.

MEASUREMENT OF THE PETROGRAPHIC PROPERTIES

For equations (1) and (2) to be operationally useful it is necessary for the petrographic variables to be expressed as meaningful numerical values; that is, all the petrographic properties must be quantitatively measured. Procedures have recently been evolved for this purpose.

The evaluation of mineral composition (m) requires identification of the constituents and an estimation of their relative proportion; the point-count technique de-

[1] Contribution No. 56-56, College of Mineral Industries, The Pennsylvania State University, Manuscript received, March 20, 1957.

[2] The porosity and permeability of these samples was determined by Core Laboratories Inc., Dallas, Texas, for the Dearborn Oil and Gas Corporation, Evansville, Indiana.

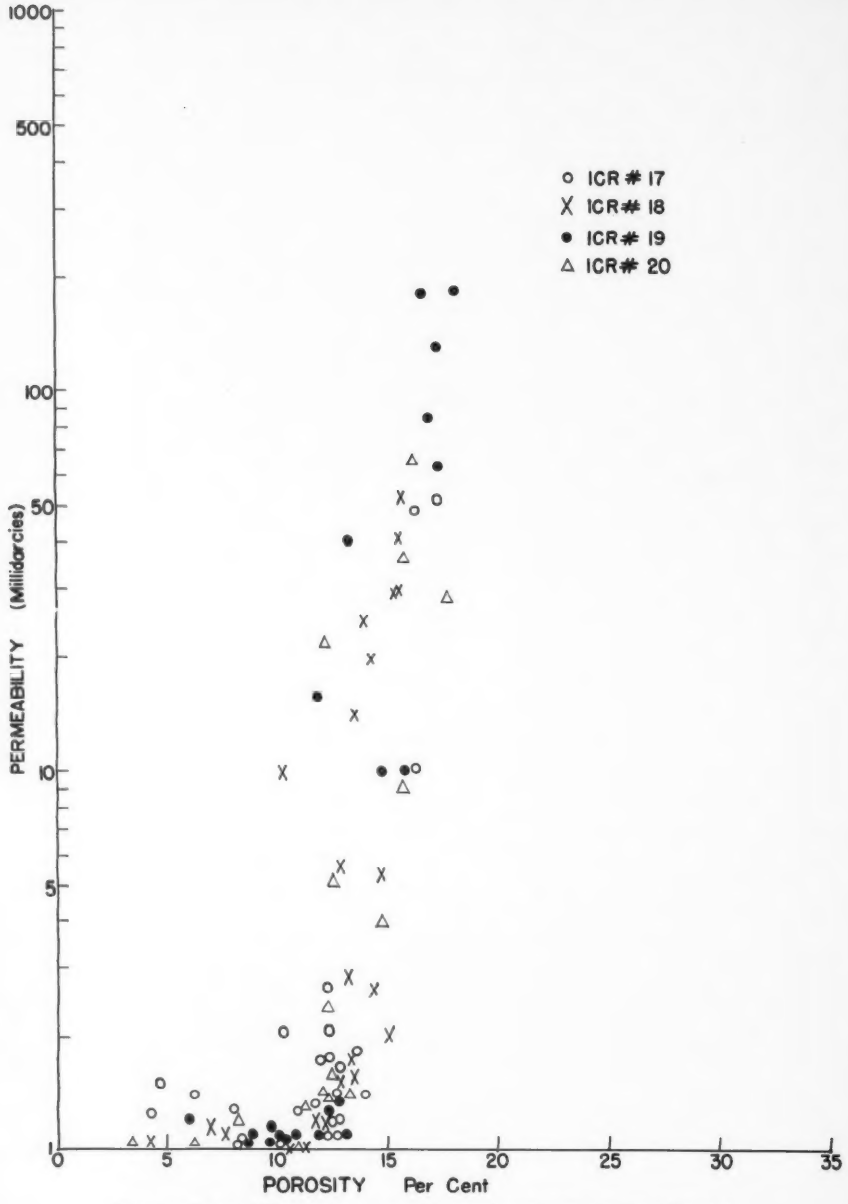

FIG. 1.—Permeability (max) vs. porosity in Cow Run Sand, West Virginia.

scribed by Chayes (1956) is the most efficient procedure for this purpose.

Grain size (s) may be measured in various ways. For this present problem, thin section measurement appears to be most suitable. Size measured in this way is defined as the long axis of quartz grains; the long axis is selected according to the operational definition given by Griffiths and Rosenfeld (1950, p. 205) and is designated the "a" axis. Shape of these same quartz grains is estimated by measuring the axis perpendicular to the long "a" axis which is defined by the same operation and is called "b." Conventionally the "shape" so measured is expressed as the ratio b/a both measured in millimeters. An alternative procedure for defining "shape" is to convert the axial measurements to the phi scale (Krumbein, 1938) and the relationship between "a" and "b" in this logarithmic scale becomes closely linear and homoscedastic (Griffiths, Cochran, Hutta and Steinmetz, 1955, p. 40).

Grain orientation (o) may be defined in terms of the perfection of orientation of the long axes of the quartz grains using the azimuthal inclination of the long "a" axis of the quartz grains to a fixed reference direction (for example see Griffiths and Rosenfeld, 1950; Hutta, 1955).

Measurement of grain packing (p) has rarely been performed, but a detailed evaluation of a measuring technique for this purpose has recently been described by Kahn (1956).

A suitable definition of the fabric of a sediment (the grain orientation and packing) can only be achieved in thin section, and hence it is convenient to estimate all five properties concurrently on the same sets of grains (traverses) in thin section. This procedure permits the use of a relatively homogeneous population of measurements thereby materially simplifying the problem of sampling.

In the present example the properties of grain orientation and packing were not evaluated although as it turned out they may be of some importance in defining the reservoir characteristics of these samples of Cow Run Sand. Despite the omission of these variables about 60 percent of the variation in porosity can be accounted for, and unless future performance requires more complete information, the main controls on this reservoir property appear to have been adequately established.

The petrographic variables which were determined are the mineral composition and the quartz grain size and shape.

SAMPLING PROGRAM

Cored sections through the Cow Run Sand were obtained from four wells (ICR numbers 17, 18, 19, 20) from the Calcutta Lease, St. Marys, West Virginia. The sand is 30–40 feet thick and megascopically similar in all four wells. Well numbers 17 and 18 were randomly sampled by 14 and 13 samples respectively while wells 19 and 20 were selectively sampled to show critical sand types. In all, 39 samples were analyzed quantitatively although some 10 additional samples were qualitatively examined.

Dark gray to black "shale" occurs above and below the sandstones in two wells. This "shale" is a highly micaceous siltstone with irregular lenses and patches cemented by carbonate. The original regular laminated texture is disturbed (probably by slumping) and this accounts for the irregularity of the carbonate patches.

The sandstones next to the shales at the top of the sand interval are "silty," with relatively small quartz grains (table 1) and large quantities of micaceous detritus. Downwards the sandstones become coarser in quartz grain size and there is a decrease in mica both as detritals and matrix. In each well the change in texture is similar, a gradual coarsening from the top downwards followed by a layer of less coarse size and then coarsening again; the coarsest sand occurs near the base of the sand interval and there appears to be an abrupt change to "shale" at the lower boundary.

In hand specimen the only other variation of note is in the cementation. The coarsest sands tend to be completely cemented by carbonate but the carbonate layers appear to be inconsistent from well to well and occur at different levels (fig. 2).

MINERAL COMPOSITION

Each sample examined in thin section contained the same mineral constituents, but the constituents varied in proportion both among and within samples, emphasiz-

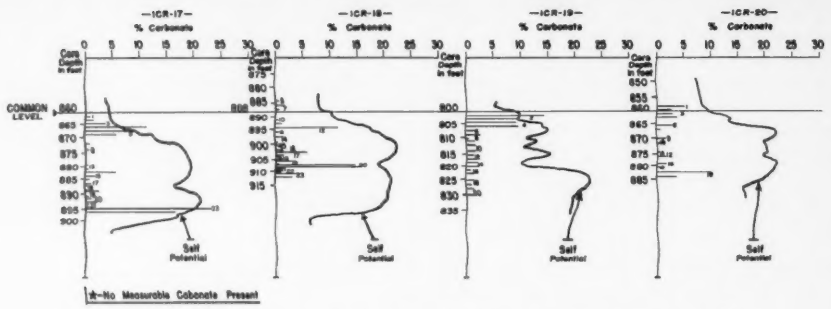

FIG. 2.—Comparison of self potential log with carbonate content in Cow Run Sand, St. Marys, West Virginia.

ing the layered character of the sands. The following minerals were identified:

Quartz—common in all samples independent of grain size; pronounced undulose extinction in most cases with the extinguished patches in the grains varying from irregular patterns to bands and thin striae. Inclusions of bubbles, micas, chlorite, both vermicular and platy, and rare dust was noted. Some of the dustier quartz grains may have been fairly fresh untwinned feldspar.

Feldspar—Clear, rectangular grains of twinned plagioclase were most common; some untwinned feldspar also occurs.

Micas—Large detrital flakes of colorless (muscovite), brown (biotite) and green (chlorite) mica occurred in every sample in small amounts. Brownish mica of varying color intensity appears most common. Similar micas occur in aggregate grains (rock fragments) and in fine-grained patches called matrix. There is probably a complete transition in size from large to very small flakes.

Rock-fragments—Fragments of quartzite showing strain extinction like the quartz are common; mica-quartz aggregates probably representing metamorphic rock-types are not uncommon and some of these when not "foliated" appear to be pieces of finer grained sandstone or siltstone. Chert is also common but is not necessarily sedimentary chert from limestone. Some grains of "chert" could be definitely diagnosed on the basis of their internal textures as secondarily silicified rocks and positive identification of volcanic textures and organic limestones was possible in the coarser grained samples. Some of this chert-like material was identified as patches of minute kaolinite books; these occurred in every slide in small amount. In addition there occur much rarer fragments of organic limestones and decomposed yellow brown grains, probably decomposed volcanic rocks. The decomposed volcanic fragments are likely to be most sensitive to changes in wetting fluid, but since they are rare they are unlikely to affect the behavior of flood waters to any great degree.

Carbonate—occurs as clastic material in these sandstones in most cases either as rock-fragments of limestones as described above or as small round organic (?) fragments. This kind of carbonate is present in all the sediments with less than 5 percent carbonate (as determined by alkalimeter). Secondarily recrystallized carbonate sometimes occurred in the same thin section as this clastic carbonate; when the carbonate content reaches 10 percent and more it is all of the recrystallized variety. The carbonate varies from brownish stained clastic organic limestone fragments to clear recrystallized calcite.

Matrix—Irregularly shaped patches of finely comminuted mica minerals like those already described occurred quite frequently; they are very common in the finer grained sandstones and form an almost continuous background with individual grains of quartz, feldspar, and rock fragments in clusters strewn through this matrix. As the grains of quartz become larger in size the amount of matrix decreases until the patches of micaceous matrix become small and isolated

in the coarser sands. In sandstones cemented by carbonate there is no matrix; presumably it is replaced by the carbonate.

Cement—The cements comprise silica and carbonate as secondarily recrystallized material; the silica occurs around quartz grains and persists even in those samples completely cemented by carbonate although some is replaced by the carbonate. Carbonate cement has already been described.

Other Minerals—Very rare grains, always less than 1 percent and generally less than 0.1 percent, of opaque material occur in each sample. In reflected light this opaque material appears to be iron hydroxide at least on the outside. Some of these grains are pyrite. Brownish stains of hydrated iron oxide also occur around some of the detrital grains and particularly associated with the clastic carbonate and in the matrix. Accessory minerals of zircon, tourmaline, and garnet are very rare constituents of the sandstones.

VARIATIONS IN PROPORTION OF THE MINERAL CONSTITUENTS

The minerals identified and described above were grouped into eight classes for point counting; six of these classes accounted for some 99 percent of the entire rock (table 1). The miscellaneous material not specifically identified during counting rarely amounts to 1 percent of the slide.

Preliminary point counting of 10 traverses of 100 grains each on 4 slides formed the basis of the sampling scheme. It was found by means of the index of dispersion (Fisher, 1948, p. 68) that 4 traverses of 200 grains each were adequate to yield a homogeneous mean proportion for quartz and rock-fragments. This was, therefore, the sampling plan followed. The four traverses actully comprised 4 pairs of 100 point counts and the pairs were selected from the 26–31 100 point traverses available on each slide.

TABLE 1.—*Composition and grain size in some cores from the Cow Run Sand, West Virginia*

Well No.	Core No.	Composition								Grain Size in Phi Units			
		Quartz	Rock Fragments	Matrix	Silica	Carbonate	Micas	Feldspar	Miscellaneous	$\bar{X}_a\phi$	$s_a\phi$	$\bar{X}_b\phi$	$s_b\phi$
ICR #17	3.1	38.00	32.90	15.90	7.90	1.80	1.60	1.20	0.80	—	—	—	—
	3.2	34.13	42.50	13.00	6.25	2.00	0.75	0.75	0.63	1.830	0.527	2.519	0.647
	5.1	39.25	31.00	12.50	5.00	10.50	0.75	1.00	0.00	1.684	0.643	2.270	0.650
	5.2	41.00	32.25	13.88	7.63	2.88	2.25	0.00	0.13	1.500	0.648	2.151	0.710
	8.1	42.88	36.38	9.00	9.75	1.13	0.25	0.63	0.00	1.363	0.517	2.021	0.472
	8.2	41.50	31.38	12.75	10.75	2.88	0.13	0.63	0.00	1.329	0.593	1.997	0.707
	13	33.35	48.75	7.13	9.38	0.63	0.13	0.50	0.13	1.384	0.578	1.870	0.637
	15.1	33.50	41.88	12.50	9.88	1.13	0.38	0.75	0.00	1.320	0.397	1.924	0.376
	15.2	29.13	54.75	6.25	5.25	2.63	0.38	1.00	0.63	1.613	0.431	2.333	0.509
	17	36.00	48.25	6.38	6.88	0.63	0.75	0.75	0.38	1.511	0.413	2.198	0.420
	18	48.38	40.13	1.13	9.35	0.13	0.00	0.88	0.00	0.876	0.516	1.472	0.494
	19	45.75	43.50	0.00	9.88	0.13	0.38	0.38	0.00	0.938	0.467	1.572	0.442
	20	38.00	53.00	0.38	5.75	0.25	0.38	2.25	0.00	0.114	0.520	0.636	0.566
	21	37.50	43.50	0.50	8.63	8.75	0.38	0.75	0.00	0.162	0.675	0.732	0.675
	23	35.63	62.13	0.00	0.88	(20.90)	0.75	0.00	0.63	0.075	0.521	0.588	0.542
ICR #18	5	34.88	33.00	18.13	11.25	0.38	1.25	1.13	0.00	1.679	0.567	2.303	0.570
	7	41.25	35.75	9.50	11.63	0.00	0.13	1.38	0.38	1.543	0.552	2.080	0.507
	10	36.38	46.75	6.13	7.88	0.38	0.75	1.75	0.00	1.561	0.517	2.175	0.489
	12	45.63	34.88	6.00	11.25	0.00	0.38	1.50	0.38	1.417	0.649	1.952	0.557
	14	41.63	33.00	13.25	11.00	0.00	0.63	0.50	0.00	1.310	0.492	1.963	0.555
	15	36.75	35.75	12.63	14.25	0.00	0.00	0.50	0.13	1.006	0.561	1.699	0.547
	16	38.00	34.50	18.50	6.75	0.00	0.38	1.88	0.00	1.311	0.412	1.922	0.508
	18	38.38	40.13	14.38	6.13	0.00	0.88	0.13	0.00	1.130	0.426	1.700	0.424
	19	40.0	38.63	13.75	6.50	0.50	0.13	0.25	0.25	0.939	0.456	1.526	0.544
	20	53.38	37.75	6.63	2.13	(27.25)	0.00	0.13	0.00	0.778	0.473	1.534	0.527
	21	45.75	31.63	11.00	11.38	0.00	0.13	0.13	0.00	0.965	0.343	1.626	0.442
	22	36.63	35.63	17.50	8.25	1.38	0.00	0.63	0.00	0.897	0.328	1.609	0.452
	23	53.00	39.13	2.75	4.50	(26.75)	0.25	0.38	0.00	0.934	0.572	1.573	0.481
ICR #19	4	38.38	42.38	7.38	6.25	2.25	2.38	1.00	0.00	1.649	0.466	2.370	0.463
	8	40.50	31.75	16.13	6.25	0.25	2.63	1.25	1.25	2.125	0.557	2.796	0.491
	14	34.38	35.63	21.25	5.63	0.00	2.00	1.13	0.00	1.906	0.460	2.530	0.467
	16	40.00	39.38	11.25	9.13	0.00	0.00	0.25	0.00	1.001	0.443	1.581	0.441
	18	39.00	33.63	14.38	12.50	0.38	0.13	0.00	0.00	0.779	0.395	1.294	0.515
ICR #20	3	26.50	51.75	6.50	8.00	4.75	0.75	1.63	0.13	2.063	0.414	2.696	0.417
	6	36.13	46.50	1.75	12.38	0.25	0.88	1.38	0.25	1.251	0.690	1.866	0.674
	9	41.00	42.38	3.75	10.88	0.13	1.38	0.25	0.25	1.417	0.655	2.022	0.674
	12	40.00	45.50	2.25	9.25	0.38	1.00	1.38	0.25	1.575	0.439	2.211	0.446
	15	41.13	42.13	5.75	9.50	0.88	0.38	0.25	0.00	1.315	0.390	1.905	0.401
	18	45.75	25.13	14.75	3.00	10.63	0.00	0.75	0.00	1.008	0.413	1.565	0.462

The mineral composition in table 1 is expressed as the mean of 4 traverses of 200 points each. Furthermore, the sample numbers 3.1, 3.2, etc. indicate samples from the top and bottom of a 6–8 inch core, and as these do not appear to differ materially, one thin section per 6–8 inches appears adequate for our purpose.

FREQUENCY DISTRIBUTIONS OF THE MINERAL CONSTITUENTS

The 39 samples, with 4 traverses in each, yield 156 estimates of each mineral constituent; these data were classified and expressed as frequency histograms. The relevant summary statistics for these frequency distributions are recorded in table 2. These values may be used as estimators of the population parameters where the frequency distribution may be matched by certain well-known distributions.

The frequency distribution for quartz in these thin sections (fig. 3a) is not significantly different from a normal distribution on the basis of cumulant (Fisher, 1948; Griffiths, 1955) statistics (g_1, g_2) or when tested by chi-square against a theoretical normal distribution with the same mean and variance ($\chi^2 = 2.05$, $P > 80$).

The frequency distribution for proportion of rock-fragments (fig. 3b) is skewed positively ($g_1 = 0.3953$; $P < 0.05$), i.e. is skewed towards high values. The kurtosis is also significantly different from normal ($g_2 = 0.8084$; $P < 0.05$); the frequencies are too low around the mean and too high on both tails. This frequency curve is also significantly different from a binomial with the same mean and variance. It seems likely that these features are due, at least in part, to a difficulty in distinguishing consistently between matrix and micaceous rock-fragments in the finer grained samples.

Feldspar and mica are comparatively rare and, superficially at least, appear to yield Poisson distributions; no attempt was made to fit these distributions. Similarly the frequency distribution of proportion of matrix appears to be heterogeneous perhaps because of the confusion with rock-fragments in the finer grained samples. The frequency distribution of proportions of silica cement (fig. 4) does not differ from a normal distribution on the basis of the cumulant values (g_1, g_2 not significant). In this respect the frequency distribution of proportion of silica resembles that in the barren samples of some Morrison sandstones from the Colorado Plateau (Griffiths and others, 1955, fig. 10, p. 22 and table 3, p. 25), although there is somewhat more silica in the Morrison than in the Cow Run Sand samples ($\bar{X} = 11.93$ and 8.35 respectively). Presumably this form of frequency distribution suggests that the distribution of silica is homogeneous in this set of samples. If the silica is redistributed, then the frequency distribution loses this character.

At least two kinds of carbonate, the discrete, clastic grains and the crystalline cementitious material occur in the Cow Run Sand; hence the frequency distribution will not be homogeneous. As a first approximation we may consider the carbonate in discrete grains to be original and Poisson in form whereas, when the carbonate is re-

TABLE 2.—*Summary statistics for grouped frequency distributions of mineral constituents*

Mineral	Mean, $\bar{X}$%	Standard Deviation, s%	Skewness[2]		Kurtosis[2]	
			Sk	g_1	K	g_2
Quartz	39.74	7.01	0.053	0.1061	−0.237	−0.200
Rock-fragments	40.13	8.92	0.197	0.3983*	0.744	0.8084*
Feldspar[1]	1.00	0.90	0.576	1.163**	0.479	0.535
Micas	0.91	0.91	0.793	1.602**	3.188	2.2998**
Matrix	9.82	6.31	0.143	0.2886	−0.795	−0.7815*
Silica	8.35	3.66	0.116	0.2332	0.183	0.2288
Carbonate	4.00	7.00	1.333	2.6910**	6.100	6.3363**

$N = 156$, comprising 4 traverses of 200 points each in 39 samples.
[1] $N = 155$; one extreme value of 9% omitted.
[2] These statistics are dimensionless.
* Significant at 5% level.
** Significant at 1% level.

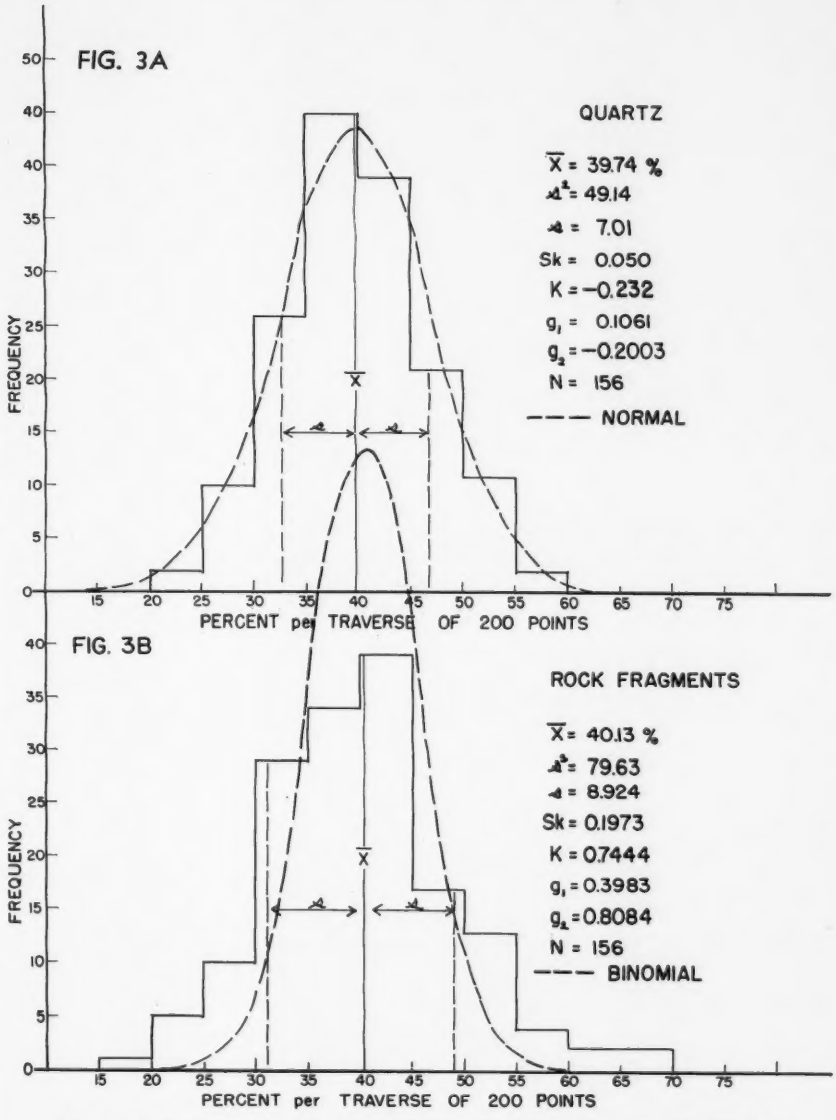

FIG. 3a.—Frequency distribution of quartz in Cow Run Sand, St. Marys, West Virginia.
b.—Frequency distribution of rock fragments in Cow Run Sand, St. Marys, West Virginia.

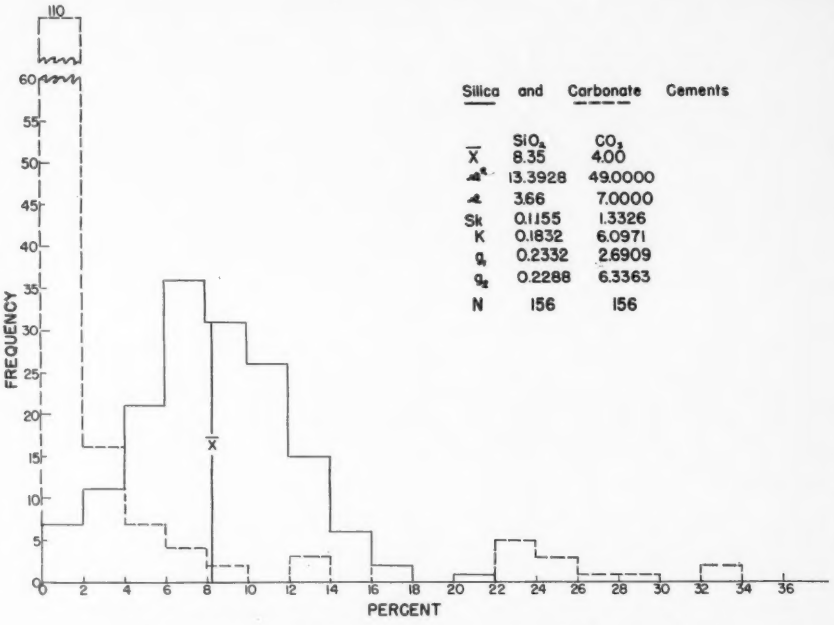

FIG. 4.—Frequency distribution of silica cement and carbonate in Cow Run Sand, West Virginia.

distributed and recrystallized as cement, it will possess a different frequency distribution. Some approach to this kind of an arrangement occurs in the Morrison samples when ore-bearing samples are compared with barren samples (Griffiths and others, 1955, fig. II). Similarly, in these samples of Cow Run Sand there is a close resemblance to a Poisson in the area of least proportion (<10 per cent carbonate) with an unusually large frequency in the range of 20 to 34 percent carbonate. It would appear that this carbonate is redistributed and secondarily crystallized. Furthermore since not all the layers of Cow Run Sand possess crystalline carbonate the origin cannot be attributed to any general process such as pressure which affected the sands as a whole after consolidation. Whatever process is invoked must have acted differently in the various layers. Presumably, migrating solutions which found access easier along coarser, more permeable layers were the carriers of this material.

Carbonate in small amounts, less than 5 percent, may occur anywhere in the sand; there are no samples with zero carbonate. Large amounts of carbonate, greater than 20 percent, occur in the coarser layers. These coarse layers with large amounts of carbonate are not persistent stratigraphically across all four wells (fig. 2) but occur as impersistent lenses. The effect of large amounts of carbonate on the self-potential of the sand is to lower it, as would be expected. Such carbonate cemented layers will act as shale breaks in these wells and, of course, do not contain oil.

SIZE OF THE QUARTZ GRAINS IN THE COW RUN SAND

The quartz grain size was determined by measuring the long and short axes of 10 grains from each of four traverses in 38 samples. The mean values per sample are listed in table 1. The four traverses in each slide were then used to estimate proportions of the mineral constituents, and an attempt

was made to sample sedimentation units by measuring 10 continuous quartz grains. In samples with large amounts of matrix, rock-fragments, or carbonate the 10 grains of quartz were not in contact and it is believed that 10 sets of 4 would have been a more correct sampling pattern for purposes of estimation of mean quartz grain size in these samples.

The summary statistics expressed in phi units are listed in table 3. The Cow Run Sand is coarser in average quartz grain size than the Pocono, Salt Wash, Berea or Oriskany (Griffiths, and others, 1955 table II–13, p. 37) but is as well sorted in terms of standard deviation as the Berea and Salt Wash. The Pocono and Oriskany are less well sorted than the Cow Run Sand.

On the basis of the cumulant statistics this grain size frequency distribution (fig. 5) is non-normal (both g_1 and g_2 exceed their respective sampling errors, $P<0.1$). Similarly a comparison of the computed normal frequency distribution with the same mean and variance yields a chi-square of 26.89 and a probability <0.01—definitely non-normal. The comparison is illustrated in figure 5 where it may be seen that the excesses and deficiencies in frequency of the observed and computed do not appear to be systematically arranged and it is suspected that the non-normalcy is largely due to an incorrect sampling pattern.

Five samples with greater than 10 percent carbonate yield a frequency distribution (fig. 5) which is also non-normal and apparently playtkurtic or flat-topped ($g_2=0.68$, $P<0.05$). We may now ask if these carbonate containing specimens contain a random sample of quartz grains from the population of quartz grains measured in the Cow Run Sand. The variances are not significantly different on the basis of an F test although they barely meet this test ($F=0.5850/0.4942=1.183$, $P>0.05$).

The confidence limits around the mean of the 1520 grains are $\overline{X}\pm 3s_{\overline{X}}=1.240\pm 0.054$ yielding a range of 1.294–1.186 phi. The mean of the carbonate samples, $\overline{X}_c=0.862$, lies well outside this range, and hence the average grain size of the quartz grains in the carbonate samples is significantly coarser than the average of the entire set of quartz grains. It is noteworthy, however, that the spreads (standard deviation) in grain size of both carbonate rich and carbonate poor samples are the same.

The "b" phi axis yields distributions which show no evidence of departure from normalcy on the basis of the cumulant statistics either in the entire set of 1520 grains or the subset of carbonate rich samples. The carbonate samples on the average are coarser than and have equal or greater spread than the entire set of quartz grains.

SHAPE OF THE QUARTZ GRAINS IN THE COW RUN SAND

The measure of quartz grain shape used here is the ratio of the short to the long axes of the quartz grains, both measured in millimeters; this statistic may be called a measure of circularity or two dimensional sphericity ($\psi_e=b/a$). The frequency distribution is illustrated in figure 6 and the summary statistics are included in table 3. The curve is non-normal and the large negative kurtosis value is almost certainly due to the unusually large excess of grains with axial

TABLE 3.—*Descriptive statistics for grain size frequency distribution in 38 samples of Cow Run Sand*

	a^ϕ axis All Samples	a^ϕ axis $CO_3>10\%$	b^ϕ axis All Samples	b^ϕ axis $CO_3>10\%$	Shape b/a All Samples
$\overline{X}$	1.2403	0.8620	1.8403	1.488	0.671
s^2	0.4942	0.5850	0.5324	0.5523	0.283
s	0.7029	0.7648	0.7296	0.7431	0.168
Sk	0.0978	0.0086	−0.0328	0.13	−0.061
K	0.5025	0.6354	0.0102	0.0658	−0.471
g_1	0.1956**	0.0173	−0.0658	0.1320	−0.121*
g_2	0.4941**	0.68*	0.0003	0.1670	−0.469**
N	1520	200	1520	200	1520

* Significant at 5% level.
** Significant at 1% level.

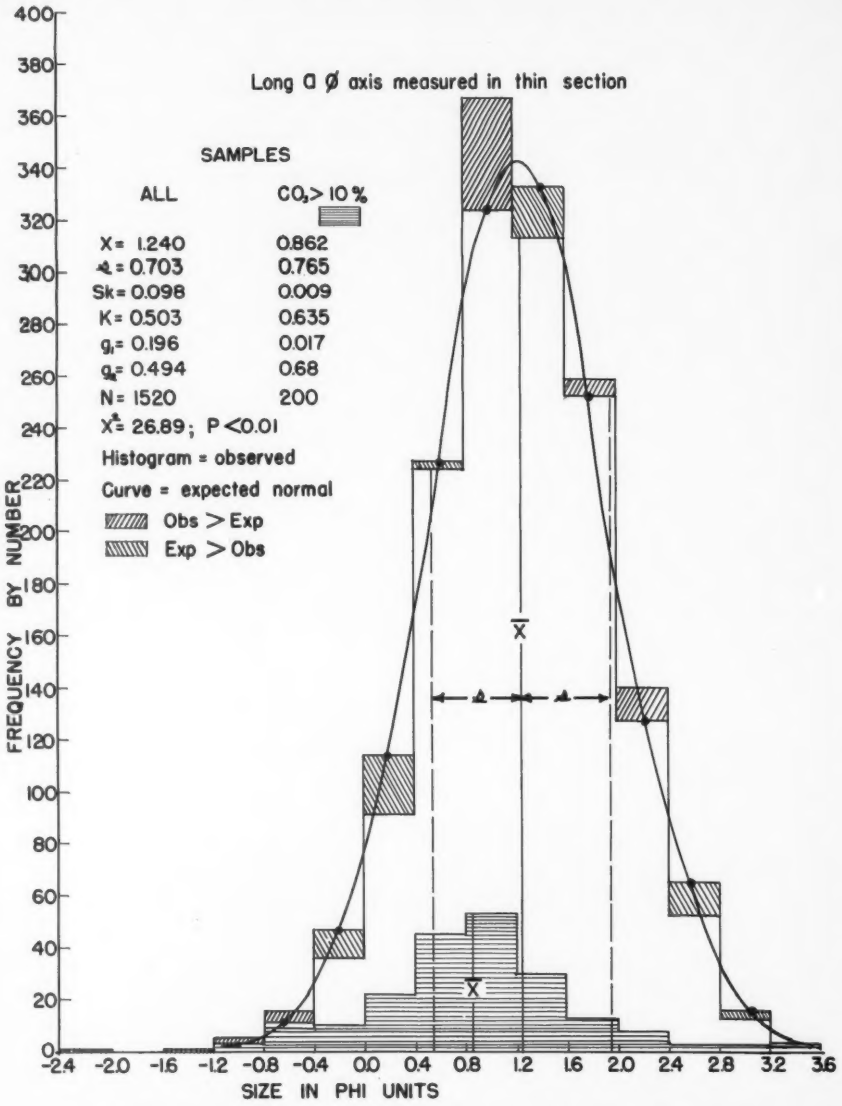

FIG. 5.—Size frequency of quartz grains in Cow Run Sand, St. Marys, West Virginia.

ratio sphericity of unity, that is, of grains which closely approach a circle.

The mean shape of 0.671 and its accompanying standard deviation of 0.168 axial ratio units is not very different from that of the quartz grains from the Pocono of Pennsylvania, the Berea oil sands in Ohio, the Bradford Sand of Pennsylvania and New York, and the Oriskany and Morrison (Salt Wash) Sandstones (Griffiths and others,

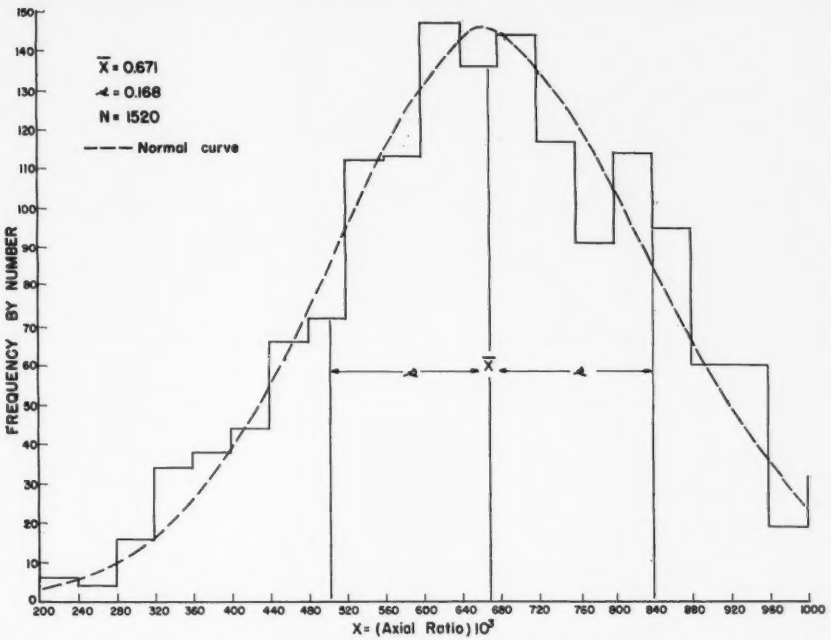

FIG. 6.—Shape (axial ratio) frequency of quartz grains in Cow Run Sand, St. Marys, West Virginia.

1955, table II-16, p. 46). There appears to be little variation in mean axial ratio shape of quartz grains in a wide variety of sandstones including low rank graywackes, quartzites, and various kinds of quartzose rocks and over a size range from around 1 to 3 phi units.

This constancy of "shape" of quartz grains as measured in thin section is strikingly illustrated when sample means in place of individual grain values are used (Griffiths and others, 1955).

RELATIONSHIPS AMONG SIZE AND SORTING OF AXIAL MEASUREMENTS

If the grain size of sediments is measured by sieving, pipette sedimentation, or indeed any indirect measuring technique, there is usually a relationship between mean size (median) and spread or sorting as measured by the percentile statistics (Griffiths, 1951a, 1951b).

On the other hand, when the sizes of quartz grains are measured directly in thin section the mean size of small sets of grains or of large sets (samples) is independent of the size-sorting measured as the standard deviation. These relationships are illustrated in table 4 and figure 7; relationship between long "*a*" axis mean size ($\overline{X}_a$) and its standard deviation (s_a) yields low values of the correlation coefficient (r); only one well (ICR no. 19) yields a significant value and this is probably due to the small number of samples ($N = 6$).

The relationship between long "*a*" axis ($\overline{X}_a$) and short "*b*" axis ($\overline{X}_b$) means is however consistently high and, of course, highly significant (fig. 7a); the values indicate between 96 and 99 percent common association in variation among both axes.

Association between mean size and its spread for any combination of axes ($\overline{X}_a$ or $\overline{X}_b$) and sorting (s_a or s_b) are low and inconsistent in sign. This variation is therefore considered to reflect sampling error around zero correlation.

The standard deviations for each axis

TABLE 4.—*Relationships among size and sorting of quartz grains in Cow Run Sand*

Well	$\bar{X}_a s_a$	$\bar{X}_a \bar{X}_b$	$\bar{X}_a s_b$	$s_a \bar{X}_b$	$s_a s_b$	$\bar{X}_b s_b$	N
17	−0.1470	0.9954**	−0.0217	−0.1789	0.8533**	−0.0512	14
18	0.4833	0.9802**	0.3471	0.4489	0.6523*	0.3806	13
19	0.8565*	0.9970**	−0.6425	0.8569*	−0.3241	−0.6776	6
20	−0.2063	0.9989**	−0.2935	−0.1801	0.9883**	−0.2712	5
All wells	0.0170	0.9927**	−0.0973	0.0071	9.7996**	−0.1151	38

Numbers in the table are values of the Pearson product-moment correlation coefficient (r); asterisks express the probability level where the coefficients are significant. The significance test is against a null hypothesis of zero correlation in the population (Fisher and Yates, table VI, p. 46).

(s_a and s_b) exhibit positive and moderate association about 42–97 percent common variation (r^2) in the two variables (fig. 7b).

One may conclude that variation in shape of quartz grains in the Cow Run Sand is small when measured as mean values of sets of grains, whether "shape" is expressed as the ratio of the axes in linear scale (millimeters) or as the degree of association in axes measured in logarithmic scale (phi units). This same conclusion is reached in studies of quartz grains in a number of other sands (Griffiths and others, 1955, RME 3122, p. 44).

INTER-RELATIONSHIPS AMONG THE PROPERTIES OF COMPOSITION, SIZE, SHAPE, AND POROSITY IN THE COW RUN SANDS, WEST VIRGINIA

Examination of the relationships among pairs of these properties represents the first step in evaluating the inter-relationships among petrographic properties and porosity; the relationship between pairs is here measured by the correlation coefficient (r) and its square, the coefficient of determination (r^2). These coefficients can, under the present circumstances, only be used as approximations because assumptions inherent

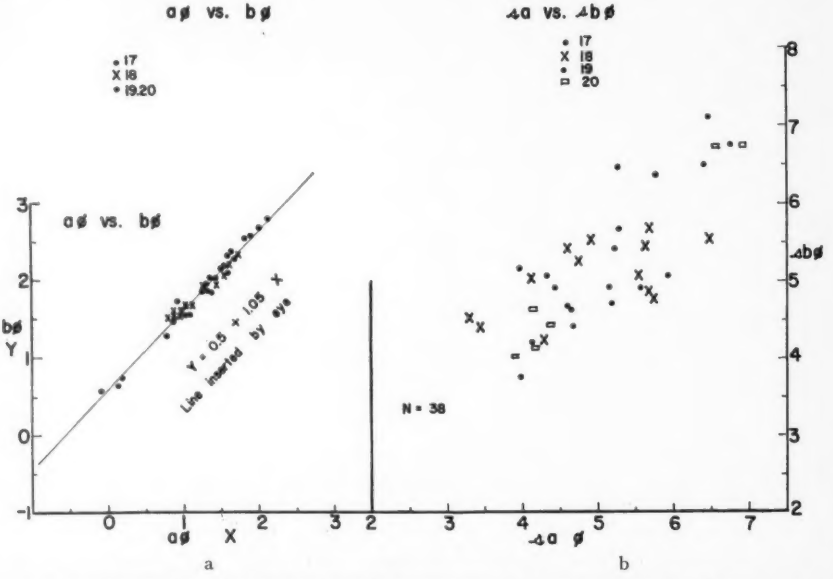

FIG. 7a.—Comparison of *a* and *b* phi axis of quartz grains in Cow Run Sand. b.—Comparison of standard deviations of *a* and *b* phi axes of quartz grains in Cow Run Sand.

in their use are not fulfilled by the data, and there is no guarantee that paired relationships are linear; furthermore, intercorrelations among the variables may mask the actual relationships between pairs. In general then, when using correlation coefficients among pairs, the results may be considered suggestive and are not conclusive without more elaborate investigation using multivariate analysis. The paired correlation coefficients are listed in table 5 and probability levels indicated by asterisks emphasize the more important relationships measured by the coefficients.

There is an inverse correlation between proportion of rock-fragments and proportion of matrix which may reflect the ambiguity involved in differentiating these items during point-counting: it may also be due to the fact that there is a real decrease in matrix content as the amount of rock-fragments increases. This in turn may be a function of grain size, that is, as the amount of matrix increases the phi mean increases (positive correlation of matrix with $\overline{X}_a$ and $\overline{X}_b$). When phi mean increases, size of quartz grains decreases; therefore amount of matrix increases with decrease in quartz grain size. Hence, as phi mean size decreases, quartz grain size increases and simultaneously amount of rock-fragments and quartz increases (negative correlations between both quartz and rock-fragments and grain size in phi units).

The only other two significant associations among the petrographic variables concerns the relationships between the axes and the standard deviations of the axes as mentioned earlier in the section on grain size and shape.

Considering the association between petrography and porosity it may be seen that as the amount of quartz increases, porosity increases (r positive and significant); as phi mean decreases porosity increases or as the quartz grain size becomes coarser the porosity increases and this holds for both axes; hence porosity increases as area of the grains increases.

TABLE 5.—*Matrix of correlation coefficients among mineral composition, size, and porosity in Cow Run Sand, West Virginia*

		Quartz X_1	Rock-frags X_2	Matrix X_3	Silica X_4	Size$_a$ X_5	Size$_b$ X_6	Sorting$_a$ X_7	Sorting$_b$ X_8	Porosity Y
Quartz	X_1	1.0	−0.4193*	−0.2488	+0.2253	−0.2996	−0.2905	+0.0739	+0.0017	+0.3994*
Rock-fragments	X_2		1.0	−0.6919**	−0.2855	−0.1296	−0.1524	+0.1278	+0.0680	−0.0373
Matrix	X_3			1.0	−0.1457	+0.3452	+0.3599	−0.4047*	−0.2503	−0.2055
Silica	X_4				1.0	−0.0748	−0.0724	+0.2874	+0.2907	+0.2649
Size$_a$	X_5					1.0	+0.9939**	−0.0319	−0.2825	−0.3832**
Size$_b$	X_6						1.0	−0.0642	−0.3119	−0.5722**
Sorting$_a$	X_7							1.0	+0.8292**	−0.2812
Sorting$_b$	X_8								1.0	−0.0879
Porosity	Y									1.0

N = 28.
* Significant r at $P_{05} > 0.374$.
** Significant r at $P_{01} > 0.478$.

RELATIONSHIPS BETWEEN POROSITY AND PETROGRAPHY

We may now attempt to elucidate the relationships between the petrographic properties and the porosity of these Cow Run

Sand samples by inserting the porosity in equation (2) (see Introduction) as the dependent variable Y.

It seems clear that when the carbonate is present as recrystallized cementitious material it plays a large role in reducing the porosity, and when it is present in large quantity it plays a dominant role in reducing the porosity. Hence as a first step the porosity was plotted against the carbonate content (determined by alkalimeter). The relationship is inverse and approximately linear (fig. 8) and is independent of geographical or stratigraphical location. When 10 percent carbonate is present the porosity is reduced to about 10 percent. Below 5 percent carbonate the porosity appears to vary independently of the carbonate and in this range nearly all the carbonate is present as clastic particles. Hence the samples with greater than 5 percent carbonate were omitted from the analysis because in samples with more than 5 percent carbonate, porosity is controlled almost entirely by carbonate content; the value of $r^2=0.83$ or about 83 percent of the porosity (Y) in these samples is explained by the variation in carbonate content.

When samples with greater than 5 percent carbonate were rejected, 28 samples remained, and the subsequent analysis refers solely to these samples. The sums of squares and products for each of eight petrographic properties and porosity were obtained, expressed in matrix form and inverted (Anderson and Bancroft, 1952, p. 197). It was obvious that some of these properties were playing no appreciable part in determining porosity, and after a number of trials and changes of order, five properties were eventually decided upon, namely, size (both $\overline{X}_a$ and $\overline{X}_b$), size-sorting of the "a" axis (s_a), and the proportion of quartz and silica. The multiple regression procedure was applied to these properties and the contribution of each factor may be expressed by means of an analysis of variance table (table 6).

It is evident that each variable except the b axis ($\overline{X}_b$) is contributing to the variation in porosity.

As an approximate measure of the contribution of each variable we may express

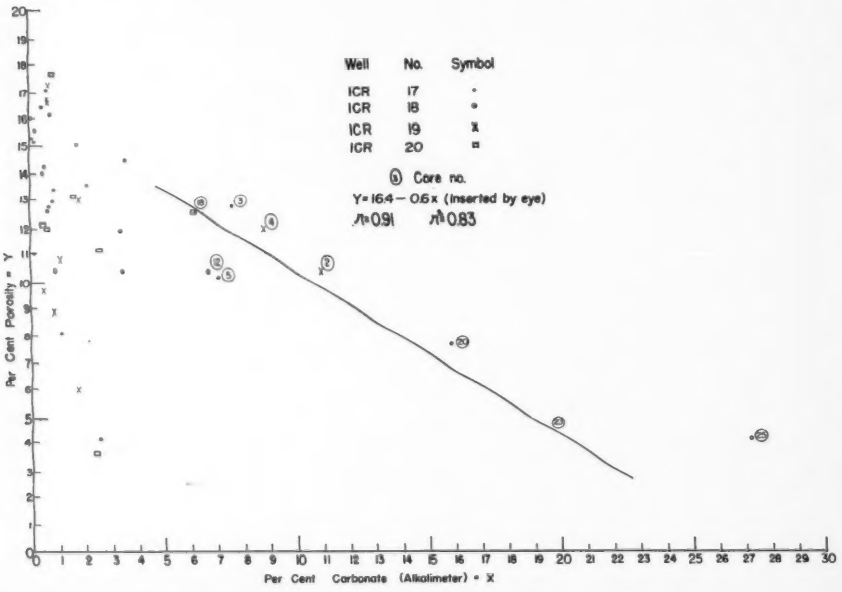

FIG. 8.—Relationship between porosity and carbonate content, Cow Run Sand, St. Marys, West Virginia.

TABLE 6.—*Multiple regression analysis of variance of size and composition on porosity in 28 samples of Cow Run Sand, St. Marys, West Virginia*

Source of Variation	Variable	Degrees of Freedom	Sums of Squares	Mean Square	F	Percentage† Explained
Grain Size ($\overline{X}_a$)	X_1	1	68.0997	68.0997	17.67***	34.0
Grain Size ($\overline{X}_b$)	X_2	1	0.9246	0.9426	<1.0	0.0
Size-Sorting (s_a)	X_3	1	17.1524	17.1524	4.45*	8.6
Quartz %	X_4	1	13.4761	13.4761	3.50	6.7
Silica %	X_5	1	15.7406	15.7406	4.08*	7.9
Cum. Total	X_{1-5}	5	115.4114	23.0823	5.99**	57.7
Residual	—	22	84.7776	3.8535	—	42.3
Total	—	27	200.1890	—	—	100.0

* Significant at the 5 percent level.
** Significant at the 1 percent level.
*** Significant at the 0.1 percent level.
† Expressed as multiple regression coefficient in percent.

the proportion of the sums of squares as a percentage of the total. In following this practice it must be emphasized that the order of the variables in the multiple regression analysis is important; thus, for example, if $\overline{X}_b$ was used as a first measure of size, then $\overline{X}_a$, because it is so highly correlated with $\overline{X}_b$, would probably add little to the relationship between size and porosity; in our case $\overline{X}_b$ is second and makes little contribution.

In the initial analysis mineral composition, particularly quartz and silica, was inserted ahead of texture but accounted for less than grain size so the order was inverted and size and sorting put first. In a second stage using both sizes ($\overline{X}_a$, $\overline{X}_b$) and quartz, silica, and rock-fragments, the last item, proportion of rock-fragments failed to contribute appreciably and so was omitted.

From table 6 it can be seen that long "*a*" axis (X_1) variation accounts for about a third (34 percent) of the variation in porosity and as mentioned above, the short "*b*" axis (X_2) contributes nothing extra. Sorting accounts for another 8.6 percent of the porosity variation and is therefore of less importance than size. Variation in proportion of quartz (X_4) accounts for an additional 6.7 percent[3] and silica despite its unfavorable position accounts for an additional 7.9 percent of the variation in porosity. From earlier trials the insertion of silica as X_4 would not eliminate either quartz proportion or long "*a*" axis so these figures may be taken as an approximate guide to the importance of the variables. Together four variables, size, size-sorting, silica, and quartz percent account for about 60 percent of the variation in porosity ($\overline{X}_b$, or X_2 in table 6 contributes a negligible proportion).

We may conclude, therefore, that the most important factors controlling the porosity of these Cow Run Sand samples are carbonate cement when it comprises more than 5 percent of the total rock and grain size, size-sorting, and silica cement when there is less than 5 percent carbonate present.

[3] This variable does not contribute significantly on the basis of the F test.

DISCUSSION

The carbonate rich cemented sandstones are coarser on the average than the uncemented sands; the distribution of carbonate cement is related to texture and is determined largely by size. It would seem likely, therefore, that the initial porosity, prior to carbonate cementation, was controlled by size, and when the coarsest and most porous sands were cemented, the porosity of the remaining uncemented sands is still controlled largely by changes in grain size.

If this is correct, fluid flow through these sands is and was largely a function of variation in texture and particularly variations in grain size. It is, of course, not possible to decide the role of the other textural properties, orientation and packing, in controlling porosity, but from information on some Berea oil sands (Emery and Griffiths, 1954) it seems likely that packing at least is important and may be of greater importance than grain size.

From the point of view of water flooding these sands it is certainly of very consider-

able value to realize that the most important factors controlling fluid flow through these sands is grain size and the cements carbonate and silica.

One qualification should be emphasized. In the above analysis it is tacitly assumed that the porosity and permeability of these sands, as measured in the laboratory, are true characteristics of the reservoir rock in the field. If the conditions in the laboratory experiments bear a close resemblance to field operating conditions then these reservoir characteristics measured in the laboratory will be applicable to field performance of the reservoir rock, and the above conclusions will be a safe guide to water-flooding.

CONCLUSIONS

The Cow Run Sand from four wells in the St. Marys area of West Virginia is a coarse grained low rank graywacke. The most important variations in petrographic character are changes in grain size, amount of matrix, and cement. Carbonate cement, in particular, varies from 5 to 28 percent by volume of the sand.

The porosity of these sands is largely determined by changes in grain size and the coarser sands are cemented completely by carbonate. In those sands containing less than 5 percent carbonate, grain size, size-sorting, silica cement, and amount of quartz play an important role and suffice to account for some 60 per cent of the variation in porosity of the uncemented sands.

The carbonate cement is secondarily recrystallized and its distribution is suggestive of original control of fluid flow (referring to fluids which precipitated the carbonate) by variations in porosity which in turn were a function of changes in grain size, the coarser sands being the more porous.

On the basis of the core analysis determinations of porosity it would appear that water-flooding will be a function of the changes in texture particularly grain size; flow will be easiest through those sands which are coarsest in grain size and are free from carbonate cement.

ACKNOWLEDGMENTS

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REFERENCES

ANDERSON, R. L., AND BANCROFT, T. A., 1952, Statistical theory in research. McGraw Hill Book Co., Inc., New York, 399 p.

CHAYES, F., 1956, Petrographic modal analysis. John Wiley & Son, New York, 113 p.

EMERY, J. R., AND GRIFFITHS, J. C., 1954, Differentiation of oil-bearing and barren sediments by quantitative petrographic analysis: Pennsylvania State Univ. Min. Ind. Expt. Sta. Bull. 64, p. 63–68.

FISHER, R. A., 1948, Statistical methods for research workers. 10th ed., Oliver & Boyd, London, 354 p.

FISHER, R. A., AND YATES, F., 1948, Statistical tables for biological, agricultural and medical research. 3rd ed., Oliver & Boyd, London, 112 p.

GRIFFITHS, J. C., 1951a, Size and sorting in some Caribbean sediments: Jour. Geology, v. 59, p. 211–243.

———, 1951b, Size and sorting in sediments (abs.): Geol. Soc. America Bull., v. 62, p. 1551.

———, 1952a, Grain size distribution and reservoir rock characteristics: Am. Assoc. Petroleum Geologists Bull., v. 36, p. 205–229.

———, 1952b, Measurement of the properties of sediments (abs.): Geol. Soc. America Bull., v. 63, p. 1256.

———, 1955, Statistics for the description of frequency distributions generated by the measurement of petrographic properties of sediments: The Compass (Sigma Gamma Epsilon), v. 32, p. 329–346.

GRIFFITHS, J. C., COCHRAN, J. A., HUTTA, J. J., AND STEINMETZ, R., 1955, Petrographical investigations of Salt Wash sediments: U. S. Atomic Energy Commission Ann. Tech. Rept., Apr. 1, 1954–Apr. 1, 1955, RME 3122, Pt. I, 77 p; Pt. II, 84 p.

GRIFFITHS, J. C., AND ROSENFELD, M. A., 1950, Progress in measurement of grain orientation in Bradford sand; Pennsylvania State Univ. Min. Ind. Expt. Sta. Bull. 56, p. 202–236.

HUTTA, J. J., 1955, Fabric and permeability of some typical sediments: Pennsylvania State Univ. Min. Ind. Expt. Sta. Bull. 68, p. 93–100.

KAHN, J. S., 1956, The analysis and distribution of the properties of packing in sand-size sediments, Pt. 1 and 2: Jour. Geology, v. 64, p. 385–395 and 578–606.

KRUMBEIN, W. C., 1938, Size frequency distributions of sediments and the normal phi curve: Jour Sedimentary Petrology, v. 8, p. 84–90.

JOURNAL OF SEDIMENTARY PETROLOGY, VOL. 28, NO. 1, PP. 31–35
FIG. 1, MARCH, 1958

ALTERATION OF VOLCANIC ASH NEAR DENVER, COLORADO[1]

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ABSTRACT

A vitric, crystal, lithic volcanic ash near Denver, Colorado, consists predominantly of fresh, highly vesicular, rhyolitic glass shards and smaller amounts of partly altered platy glass shards. The alteration products of the platy shards are predominantly illite randomly interlayered with a small amount of montmorillonite and also containing a small amount of free montmorillonite. Among the lithic and crystal particles in the ash is biotite, probably of volcanic origin, which is partly altered to vermiculite, part of which is randomly interlayered with biotite. Some of the altered biotite crystals are long and vermicular and appear to be authigenic.

INTRODUCTION

Illite is one of the predominating constituents of felsic volcanic ash found near Denver, Colorado.[2] Inasmuch as montmorillonite is the common clay mineral alteration product of felsic volcanic ash, the authors thought the presence in this ash of large amounts of illite was worth reporting.

Minerals other than montmorillonite are found frequently enough to demand separate investigations of the mineralogy of clayey pyroclastic deposits. Writing on altered volcanic ash, Grim (1953, p. 362) states, "Other clay minerals, particularly *illite* and *kaolinite*, are present in many bentonites sometimes in amounts up to about 50 percent of the total clay-mineral content." Keller (1956, p. 2702) says that *kaolinite will develop from volcanic ash* where leaching is sufficiently thorough, and cites examples from the United States and Japan. Bramlette and Posnjak (1933, p. 167–171) point out that the zeolite clinoptilolite (a high-silica heulandite) is a common alteration product of incompletely altered, vitric, rhyolitic pyroclastic rocks. Bradley (1929, p. 1–7) describes analcite and apophyllite resulting from the alteration of volcanic ash that fell into the ancient Green River lakes in Utah, Colorado, and Wyoming. Ross (1941, p. 627–629) describes analcite and nontronite from Wikieup, Arizona, that were derived from glassy volcanic ash that evidently fell into a sodium-rich playa. The authors have also found pyroclastic rocks from the western United States altered to a wide variety of clay minerals and zeolites.

The ash near Denver was first described by C. B. Hunt, (1954, p. 96) as a 2-foot bed of volcanic ash interbedded with gravels of Pliocene or Pleistocene age. Hunt's site, about 8 miles southwest of Denver, in the NE corner of sec. 12, T. 5 S., R. 69 W., was visited by Van Horn in December 1955. At the time grading operations had left only one small outcrop of ash about one foot thick and 10 feet long. Field work by Van Horn in the vicinity of Golden, Colorado, 12 miles northwest of the ash deposit described here, uncovered four other volcanic ash deposits that are similar in field appearance and stratigraphic position to the deposit described here. These deposits are exposed in a gravel pit in the SE¼ sec. 3, T. 4 S., R. 70 W.; in a road cut at the corner of Gregory Drive and Gold Cove Circle in Golden; in a prospect trench in the SW¼ sec. 28, T. 3 S., R. 70 W.; and at the west end of a gravel pit in the NE¼ sec. 32, T. 2 S., R. 70 W. They have not been analyzed in sufficient detail for comparison with the ash described in this paper.

Volcanic ash deposits similar to those

[1] Publication authorized by the Director, U. S. Geological Survey. Manuscript received September 12, 1957.

[2] Yoder and Eugster (1955, p. 249–256) found that all samples described as illite that they examined could be shown to be a mica polymorph and (or) a mixed-layered mica polymorph and montmorillonite. They conclude that the term illite should be used only as a field term. Inasmuch as the polymorphic forms of mica in the ash were not identified, the term illite is used in this paper as a general term for mica clay minerals with nonexpanding structures that show, by absence of hkl X-ray diffraction peaks, less crystallinity than normal micas and a more or less broad, asymmetrical 10 Å X-ray diffraction peak. Illite contains less K_2O and generally more water than normal micas.

near Denver have been described in Kansas and neighboring states by Swineford and Frye (1946), Swineford (1949), Carey, Frye, Plummer and Swineford (1952), and Swineford, Frye and Leonard (1955).

LITHOLOGY

The ash southwest of Denver is very pale orange (10 YR 8/2)[3] in color, poorly bedded, and friable. It consists of glass shards and mineral and rock fragments mixed in proportions that vary from bed to bed. The most altered ash bed consists of an exceedingly fine-grained, clayey matrix enclosing 5 to 10 percent unaltered, sand-size, transparent, pumiceous, and highly vesicular shards and about 15 percent silt- and sand-size grains, mostly quartz and sanidine, but also including minor amounts of oligoclase, microcline, hornblende, augite, rutile, zircon, shale, chert, and hematite. Fresh water diatoms are of rare occurrence in sparse, matrix-rich clayey laminations, 1 to 2 mm thick in these beds.

In the least altered beds the proportion of unaltered, highly vesicular shards increases to about 60 percent; the proportion of silt- and sand-size minerals and rock fragments increases slightly, and about 20 percent of the ash seems to be partly altered, platy shards with rounded and (or) straight, jagged edges. Micaceous material is also present.

Glass Shards

The maximum diameter of the unaltered, transparent shards is 0.7 mm, but the diameters of most are between 0.13 and 0.35 mm. The index of refraction of the fresh shards is $1.496 \pm .002$; no variations from this range were detected. The fresh shards contain both parallel, elongated, cylindrical vesicles of small diameter (giving the shard a crude fibrous, pumiceous appearance) and large spherical vesicles of greater diameter than the shard; i.e., the curved boundaries of the shards are parts of surfaces of large bubbles.

Most of the platy shards in the least altered ash beds are between 0.05 and 0.35 mm in diameter; the largest of them are 0.5 mm in diameter. Microscopic examination of adsorption of the organic dyes, malachite green and safrinine Y, before and after acid-treatment, shows that most of the shards are more or less altered (Faust, 1940, p. 1–21; Meilenz and King, 1951, p. 1–21). Some shards show patchy staining—part of the shard may be unstained, hence unaltered, and the rest of it may show different intensities of dye adsorption, indicating partial alteration. Thus most of the platy shards in the least altered ash appear earthy and white in reflected light; the shards appear translucent to transparent and yellow brown in transmitted light. In contrast the highly vesicular shards show no dye adsorption whatever and are colorless and highly transparent.

The index of refraction of almost all of the unaltered platy shards is 1.522 ± 0.002, but a few of them have an index of refraction of 1.526 ± 0.002. They are generally isotropic or show a faint hazy light or a few weak specks of light under crossed nicols. The highly altered platy shards contain numerous tiny laths that have straight extinction and a moderate birefringence. In this and many other aspects they are similar to the matrix of the most altered ash. Consequently although no platy shards were identified with certainty in the most altered ash it is believed that the matrix was derived by alteration of platy shards.

Alteration Product of the Platy Shards

The alteration product of the platy shards was investigated by X-ray diffraction. The sample of ash was passed through a Franz magnetic separator operating at its strongest magnetic intensity to remove most of the large micaceous crystals as well as small amounts of hematite, hornblende, augite, dark shale, and other iron-bearing constituents. Samples of the nonmagnetic portion (principally ash shards) were prepared for X-ray study from a smaller-than-two-micron fraction by washing the sample with water containing a small amount of sodium metaphosphate. Although some of the large micaceous crystals remained in the nonmagnetic portion, particularly those that were low in iron content and had a bleached appearance, it is believed that their large size kept most of them out of the smaller-than-two-micron fraction. Concentration of

[3] Color designation from E. N. Goddard, and others, 1948, Rock color chart: National Research Council.

the shards by use of the float-sink method with liquids of controlled density was not attempted in order to avoid reactions between organic liquids and clay minerals. The smaller-than-two-micron fraction was found to consist largely of illite randomly interlayered with a small amount of montmorillonite (also known as "mixed-layered illite-montmorillonite") and also of a small amount of montmorillonite not interlayered with illite.

X-ray diffraction powder patterns obtained on oriented samples with a Norelco Diffractometer using copper K alpha radiation are shown in figure 1. The presence of an expanding-lattice clay mineral (montmorillonite) interlayered with illite is shown by the basal spacing of 10.2 Å (fig. 1A), which is slightly greater than that for free illite, and its shift to 11.0 Å (fig. 1B) upon glyceration. The small amount of free montmorillonite is shown by its basal spacing at about 15.7 Å (fig. 1A) which expands to about 18.4 Å (fig. 1B) upon glyceration.

Stain tests with organic dyes also suggest a high illite content. On acid-treated and washed shards, malachite green stains greenish yellow, whereas safranine Y stains red and red-purple (Mielenz and King, 1951, p. 13).

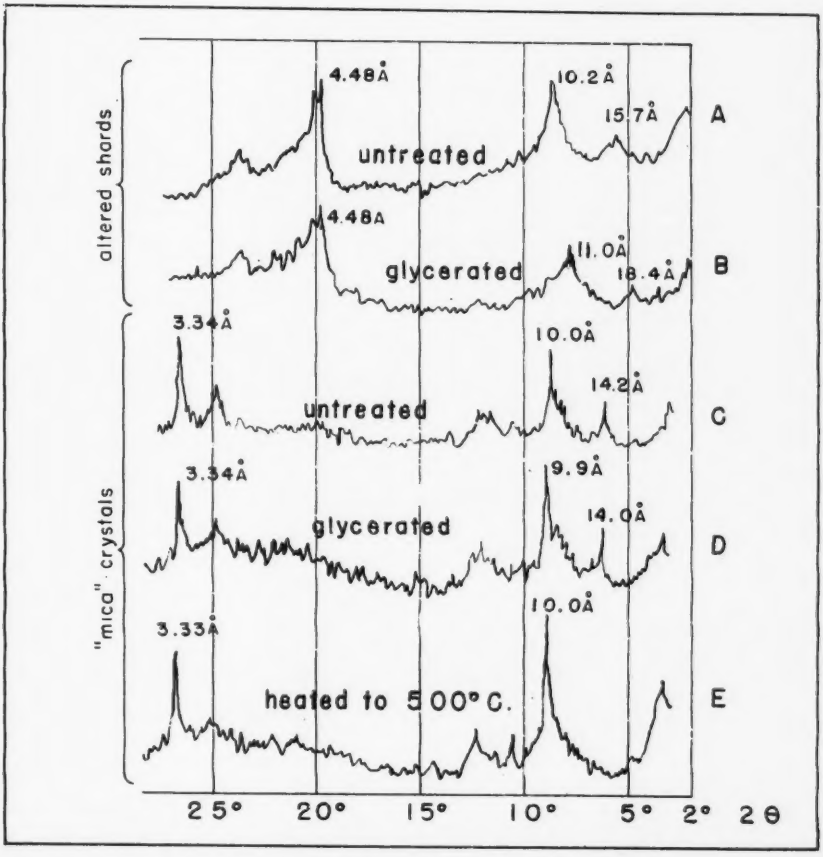

FIG. 1.—X-ray diffractometer diagrams of oriented aggregates.

Matrix of the Most-Altered Ash

X-ray diffraction analysis was made on oriented aggregates of particles smaller-than-two-microns and on particles smaller than about 0.5 micron. The coarser fraction yields X-ray diffractometer diagrams almost identical to those obtained from the alteration products of partly altered platy shards (fig. 1, A, B). The finer fraction yields X-ray diffractometer diagrams (not reproduced in this paper) which suggest that mixed-layered montmorillonite-illite (i. e., predominantly montmorillonite) is the chief constituent and mixed-layered illite-montmorillonite (i. e., predominantly illite) is a minor constituent.

The untreated oriented aggregate of the smaller-than-two-micron fraction used for X-ray diffraction analysis was examined under the petrographic microscope. Despite its high content of illite the material appears to be only faintly birefringent and has an index of refraction of 1.53 $\pm$0.004. On the other hand Grim (1953, p. 279, 284) gives the following optical properties for illites: index of refraction, alpha 1.545 to 1.62, gamma 1.57 to 1.67; birefringence 0.022 to 0.055. The low values for the illite in the ash are probably due, in part, to the occurrence of the illite in a mixed-layered form and to the presence of additional montmorillonite. Optical properties are not reliable in identification of mixed-layered clay minerals. The low birefringence may also be due to the small size of the crystals and their orientation in the prepared aggregates.

Coarse-Grained Micaceous Material

Micaceous crystals appear in the least altered ash as thin, hexagonal plates, up to 2 mm in diameter, and also as fragile, hexagonal, vermicular prisms greatly elongated perpendicular to the cleavage. X-ray diffraction analysis suggests that they consist of hydrobiotite (mixed-layered biotite and vermiculite) and thick layers of relatively pure biotite and vermiculite. The presence of several components is substantiated by microscopic examination which reveals a wide variation in color, indices of refraction, and 2V.

X-ray diffraction powder patterns obtained from a pulverized and oriented mixture of both the plates and the vermicular micaceous crystals are shown in figure 1 (C, D, E). The sharp peaks at 10 Å and 3.34 Å suggest basal spacings of free mica. The distinct spacing at 14 Å (fig. 1C), which is unchanged by glyceration (fig. 1D), but which disappears, evidently collapsing to about the 10 Å spacing upon heating to 500° C (fig. 1E), suggests vermiculite (Hathaway, 1955, p. 76; Weiss and Rowland, 1956, p. 899–914; Walker, 1950, p. 76). The series of peaks tailing off on the higher-spacing side of the 10 Å peak (fig. 1C), which do not expand with glyceration (fig. 1D), suggest random inter-layering of mica and vermiculite and variation in the mixed-layered composition.

The micaceous crystals were probably originally biotite of volcanic origin. The present delicate euhedral vermicular crystals seem to be authigenic in origin. They probably formed by expansion of vermiculite.

CONCLUSIONS

The presence in the ash of two distinct types of shards intimates that the ash is the product of two separate eruptions. The alteration of the white, earthy, platy shards must have taken place prior to the commingling of the two types of shards, because the glass in the fresh shards is probably of the same order of susceptibility to alteration as the originally fresh glass in the platy shards. It is probable that the fresh shards would likewise have been altered by the environment that altered volcanic biotite to vermiculite, and it is also probable that the alteration of the biotite took place prior to mixing with the fresh shards. Consequently, the platy, partly altered shards and the micaceous crystals probably represent an earlier eruption than that represented by the fresh shards. The presence of rounded grains, especially of chert, shale, and microcline, which are similar to those in the sand and gravel interbedded with the ash, points to reworking and mixing with nonvolcanic material after the ash settled out of the air. Diatoms suggest a fresh-water environment.

The differences between the environmental conditions that favor alteration of silica-bearing rocks to illite and those that favor alteration to montmorillonite are not well understood. Stagnant, alkaline water and the availability of ions of magnesium, cal-

cium, and iron are usually cited as conditions necessary for the formation of montmorillonite (Keller, 1956, p. 2702). The presence of potassium and a nonacid environment, but not necessarily stagnant water, are suggested as conditions favoring the formation of illite (Keller, 1956, p. 2703). Grim (1953, p. 363) states that in order to form bentonite it is probably necessary for the volcanic ash to fall into water and that the ash must have a moderate magnesium content in order to alter to montmorillonite. Although no quantitative analysis is available for the ash near Denver, Swineford, Frye, and Leonard (1955, p. 252, 257) show that the magnesium content of Miocene and Pliocene volcanic ash of Kansas and vicinity is much lower than that of most bentonites and they suggest that magnesium must be added from another source, such as a marine environment, to form montmorillonite from the ash. They also show (p. 257) that the potassium content of the ash deposits is substantial (mean K_2O content in 48 samples in 5.53 percent; standard deviation is 0.83) and is approximately four times greater than the sodium content. Evidently alteration conditions in the probably nonmarine environment of the older, platy shards in the ash near Denver were not generally favorable or continuously favorable for the formation of montmorillonite. The alteration of the older, platy shards to illite might have occurred because potassium was so readily available upon decomposition of the glass and because of a lack of additional magnesium, or for other unknown reasons. On the other hand the first alteration product of the glass may have been montmorillonite which subsequently altered in large part to illite.

The alteration conditions necessary to form vermiculite from biotite are not well established either. Walker (1950, p. 79) states that vermiculite forms from "clay-biotite" in soils derived from felsic igneous rocks irrespective of drainage conditions.

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REFERENCES

Bradley, W. H., 1929, The occurrence and origin of analcite and meerschaum beds in the Green River Formation of Utah, Colorado, and Wyoming: U. S. Geol. Survey Prof. Paper 158a, p. 1–7.

Bramlette, M. N., and Posnjak, E., 1933, Zeolitic alteration of pyroclastics: Am. Mineralogist, v. 18, no. 4, p. 167–171.

Carey, J. S., Frye, J. C., Plummer, N., and Swineford, A., 1952, Kansas volcanic ash resources: Kansas Geol. Survey Bull. 96, pt. 1, p. 1–68.

Faust, G. T., 1940, Staining of clay minerals as a rapid means of identification in natural and beneficiated products: U. S. Bur. Mines Rept. Inv. R. I. 3522, p. 1–21.

Grim, R. E., 1953, Clay mineralogy. McGraw-Hill Book Co., Inc., New York, 384 p.

Hathaway, J. C., 1955, Studies of some vermiculite-type clay minerals: *in* Clays and clay minerals, Nat. Acad. Sci.—Nat. Research Council Publ. 395, p. 74–86.

Hunt, C. B., 1954, Pleistocene and Recent deposits in the Denver area, Colo.: U. S. Geol. Survey Bull. 996-C, p. 91–140.

Keller, W. D., 1956, Clay minerals as influenced by environments of their formation: Am. Assoc. Petroleum Geologist Bull., v. 40, p. 2689–2710.

Mielenz, R. C., and King, M. E., 1951, Identification of clay minerals by staining tests: Am. Soc. Test. Mat. Proc., v. 51, p. 1–21.

Ross, C. S., 1941, Sedimentary analcite: Am. Mineralogist, v. 26, p. 627–629.

Swineford, A., 1949, Source area of Great Plains Pleistocene volcanic ash: Jour. Geology, v. 57, p. 307–311.

Swineford, A., and Frye, J. C., 1946, Petrographic comparison of Pliocene and Pleistocene volcanic ash from western Kansas: Kansas Geol. Survey Bull., v. 64, pt. 1, p. 1–32.

Swineford, A., Frye, J. C., and Leonard, A. B., 1955, Petrography of the late Tertiary volcanic ash falls in the central Great Plains: Jour. Sedimentary Petrology, v. 25, p. 243–261.

Walker, G. F., 1950, Trioctahedral minerals in the soil-clays of northeast Scotland: Mineralog. Mag., v. 29, no. 208, p. 72–84.

Weiss, E. J., and Rowland, R. A., 1956, Effect of heat on vermiculite and mixed-layered vermiculite-chlorite: Am. Mineralogist, v. 41, p. 899–914.

Yoder, H. S., and Eugster, H. P., 1955, Synthetic and natural muscovites: Geochimica et Cosmochimica Acta, v. 8, no. 5–6, p. 225–280.

JOURNAL OF SEDIMENTARY PETROLOGY, VOL. 28, NO. 1, PP. 36–39
FIG. 1, MARCH, 1958

SIZE DISTRIBUTIONS OF ZIRCON GRAINS IN SOME SAMPLES OF THE LOWER BEAUMONT CLAY[1]

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ABSTRACT

Heavy minerals of a clayey portion of the lower Beaumont Formation at Houston, Texas, consist largely of well-rounded grains of resistant minerals, such as zircon, tourmaline, and rutile. The zircon grains are well sorted, and their size distribution exhibits no apparent skewness. The study indicates that the heavy minerals were derived from sedimentary rocks in the drainage areas of the Brazos and Trinity Rivers, and the types of heavy minerals in the clay and their size distributions are largely controlled by these source rocks.

The methods used in separating and measuring the heavy minerals are described in detail.

INTRODUCTION

The Beaumont Clay is a late Pleistocene formation which crops out extensively along the Gulf Coast from Louisiana to northeastern Mexico. The formation is predominantly a clay, with irregular lentils and stringers of fine sand. The clay contains a very small amount of heavy minerals. It is with these minerals that the present study is concerned.

All sixteen samples used in the study were taken from the campus of The Rice Institute, Houston, Texas, at a depth of 0 to 11 feet below the surface. The samples represent a stratigraphic position a few tens of feet above the unconformable Lissie contact, and thus are from the lower part of the Beaumont Formation (in the classification of Hayes and Kennedy, 1903). The samples may also be placed stratigraphically in the Oberlin Formation (as defined by Doering, 1956). All samples are from an area of clays formed between the distributary systems of the ancestral Brazos and Trinity Rivers; (for further discussion of these river systems see Barton, 1930).

The object of the present paper is to describe the heavy mineral content and the size distributions of the zircon grains in the studied samples. The techniques used in separating and measuring the heavy minerals are described in the appendix.

The present study was supported by the Harry Carothers Wiess fund of the Department of Geology of The Rice Institute. Further studies of the size distributions of heavy minerals in sediments are currently being supported by the same fund. The writers express their thanks to Dr. Carey Croneis for calling their attention to the importance of studies of the Beaumont Clay.

[1] Manuscript received June 5, 1957.

ANALYTICAL RESULTS

Clay minerals comprise about 90% of all samples. The remaining 10% of each sample consists almost wholly of quartz with very minor amounts of heavy minerals.

The heavy mineral suite consists of zircon, tourmaline, rutile, garnet, kyanite, staurolite, and opaque minerals. Data on the abundances of the nonopaque minerals in the sixteen samples studied are shown in table 1. Most of the heavy mineral grains are well rounded, though some of the zircons are nearly euhedral. The heavy mineral assemblage studied in the present work is similar to the kyanite zone assemblage of Cogen (1940). The heavy minerals are also very similar to those reported by Bullard (1942) as present in the Brazos and Trinity Rivers.

The size distributions of the zircon grains in each of the sixteen samples are shown in

TABLE 1.—*Abundance of nonopaque heavy minerals in sixteen samples of the lower Beaumont Clay*

Mineral	Average Abundance	Range of Abundances
Zircon	52.8	45.0–61.0
Tourmaline	33.7	24.0–42.0
Rutile	7.7	12.0– 4.3
Garnet	2.6	6.7– 0.7
Kyanite	1.8	4.0– 0.0
Staurolite	1.3	3.0– 0.3

figure 1. Data on the median size, sorting coefficient, and skewness of the size distributions are shown in table 2. As described in the appendix, all parameters are measured from frequency distributions of the number of zircon grains in the various size grades rather than on the weight of the grains.

As shown in figure 1 and table 2, the zircon grains in all samples are very well sorted. In many samples only two size grades contain appreciable quantities of zircon. This restriction of the zircon grains to a small number of size grades makes measurements of skewness difficult, but from the few points available on the size distribution curves, it appears that the zircon grains in most samples are roughly log-normally distributed.

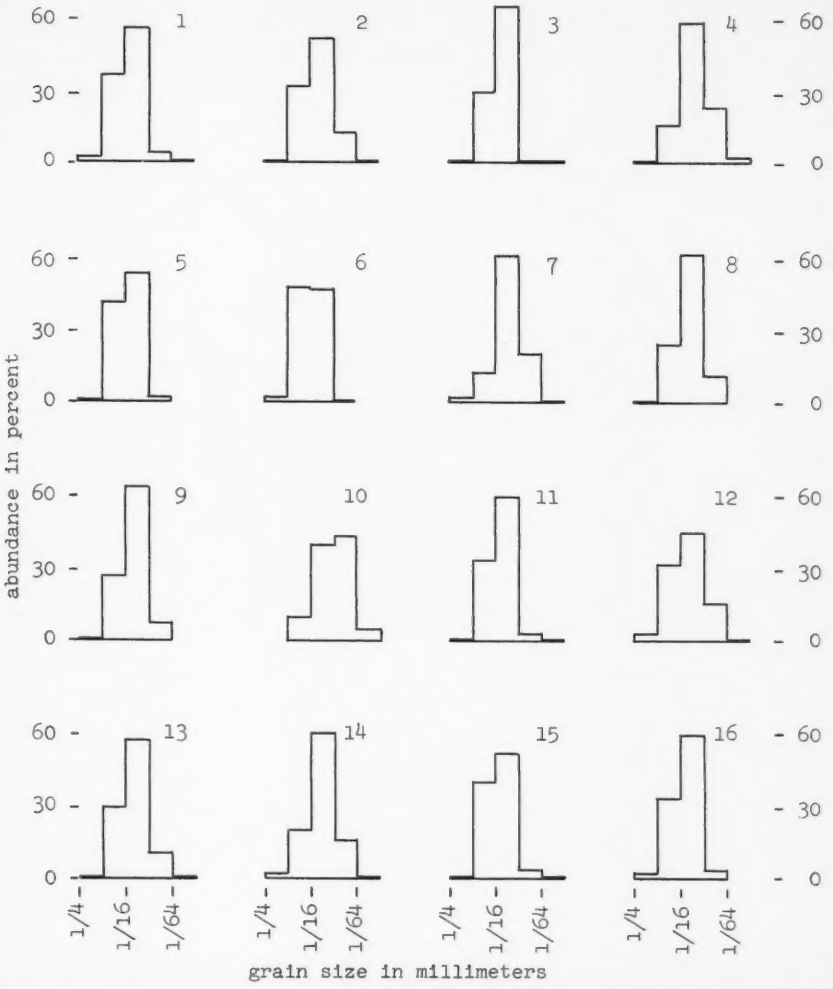

FIG. 1.—Size distributions of zircon grains in 16 samples of the Beaumont Clay at Houston, Texas.

DISCUSSION

The facts to be explained in outlining the sedimentary history of the samples of the lower Beaumont Formation examined in the present study are as follows:

1.—The nonopaque heavy minerals in the clay are stable varieties.
2.—Most of the heavy mineral grains are well rounded.
3.—The zircon grains are well sorted and roughly log-normally distributed.
4.—The varieties of heavy minerals in the clay are similar to those in the modern Brazos and Trinity River sands.
5.—The modern Brazos and Trinity Rivers, between which the samples used in the present study were taken, drain areas of sedimentary rocks.

The samples studied in the present work are apparently part of the interdistributary clays formed between distributaries of the ancestral Brazos and Trinity Rivers. That the heavy minerals in these clays were derived from the sedimentary areas drained by the two rivers is shown by the roundness of the grains and the absence of unstable minerals, both of which features indicate reworking of sedimentary materials.

The median size and size distribution of the zircon grains in the samples investigated was probably controlled largely by the nature of the source rocks and the effect of river transportation on the grains. The similarity between the types of heavy minerals in the clay and in the modern river sands indicates that the local depositional environment exercised little influence on the heavy mineral suite (assuming that the minerals in the modern rivers are similar to those in the rivers at the time the clay was deposited). Thus, the roughly log-normal distribution of the zircon grains in the clay may be solely a function of the distribution of these grains in the river load and in the source rocks. Possibly some of the coarser zircon grains in the river load were deposited in the coarser sediments along the distributary channels and did not reach the depositional environment of the interdistributary clays, but this process did not cause the size distributions in the clay to be negatively skewed.

TABLE 2.—*Median size, sorting coefficient, and skewness of the size distributions of zircon grains in sixteen samples of the lower Beaumont Clay*

	Average Value	Range of Values
Median Size (M)	0.051 mm	0.066–0.032 mm
Sorting Coefficient $\sqrt{Q_3/Q_1}$	1.31	1.38 –1.21
Skewness Q_3Q_1/M^2	0.997	1.05 –0.975

APPENDIX: PROCEDURE

The procedures used in studying the heavy minerals of the Beaumont Clay are as follows:

1.—About 15 grams of each sample were crushed in a porcelain mortar and pestle. The scarcity of fractured grains in the final heavy mineral separate indicated that this crushing did not affect the measured size distributions of the zircon grains.

2.—The crushed material was dispersed by boiling for about 20 minutes in a solution of 1 normal sodium hydroxide. Zircon samples tested by this procedure showed that the sodium hydroxide had no apparent effect on the grains.

3.—Clayey material was removed by allowing the sediment to settle for 2½ minutes in a beaker filled with water so that 1 inch of water remained above the deposited material. This water was then siphoned off, and the settling process was repeated until the liquid above the deposited material was essentially clear. By this procedure no zircon grains were removed of sufficient size and abundance to affect appreciably the measured size distributions in the size range studied. The writers were unable to perform an effective separation of the heavy minerals from the samples without this prior removal of clayey material.

4.—Following removal of the clay, the sample was dried and then boiled for 20 minutes in a 20 ml solution of concentrated hydrochloric acid containing 10 grams of stannous chloride. This procedure removed both calcite and iron oxide, both of which were found to hinder the bromoform separation of the heavy minerals. The acid probably did not affect the size distributions of the zircon grains and had little or no effect on the other heavy minerals present in the samples. (For a discussion of the effects of

acid treatment on heavy minerals see Reed, 1924, and Krumbein and Pettijohn, 1938, p. 355.)

5.—After removal of clay, iron oxide, and calcite, the samples were dried and were in condition for separation of the heavy minerals in bromoform. All samples were centrifuged in celluloid tubes at about 2500 rpm for 5 minutes, stirred, and recentrifuged three or four times. The bromoform was then frozen, and the heavy minerals were removed by cutting the tube between the heavy and light fractions, melting the bromoform, and filtering. After melting the bromoform, washing both light and heavy minerals with acetone and then water, and drying, the light fractions were again taken through the centrifuging sequence and the heavy fractions saved. Three such sequences of centrifuging and heavy mineral removal were performed on each sample, and finally, the three heavy mineral separates from each sample were combined and mounted in balsam. For each sample, the amount of heavy minerals separated in each sequence of centrifuging decreased from a comparatively large quantity in the first separate to an insignificant amount in the third separation. The writers found that more and smaller heavy minerals were separated by centrifuging than by gravitative settling.

6.—Both relative percentages of the various heavy minerals and the abundance of zircon in the different size grades were determined by grain counts on balsam slides. Mineral percentages were determined from a count of 300 grains, and size distributions were determined from measurement of the maximum diameters of 300 zircon grains. Preliminary tests showed that percentages obtained from counts of 300, 400, 500, and 600 grains showed no appreciable differences. (For further discussions of grain counts see Dryden, 1931, and Krumbein and Pettijohn, 1938, pp. 469–474.)

7.—Quartile parameters for the size distribution of the zircon grains were determined from frequency distribution curves plotted on logarithmic probability paper.

REFERENCES

BARTON, D. C., 1930, Deltaic coastal plain of southeast Texas: Geol. Soc. America Bull., v. 41, p. 359–382.

BULLARD, F. M., 1942, Source of beach and river sands on Gulf Coast of Texas: Geol. Soc. America Bull., v. 53, p. 1021–1044.

COGEN, W. M., 1940, Heavy mineral zones of Louisiana and Texas Gulf Coast sediments: Am. Assoc. Petroleum Geologists Bull., v. 24, p. 2069–2101.

DOERING, J. A., 1956, Review of Quaternary surface formations of Gulf Coast region: Am. Assoc. Petroleum Geologists Bull., v. 40, p. 1816–1862.

DRYDEN, A. L., 1931, Accuracy in percentage representation of heavy mineral frequencies: Nat. Acad. Sci. Proc., v. 17, p. 233–238.

HAYES, C. W., AND KENNEDY, W., 1903, Oil fields of the Texas-Louisiana Gulf Coastal plain: U. S. Geol. Survey Bull. No. 212, 174 p.

KRUMBEIN, W. C., AND PETTIJOHN, F. J., 1938, Manual of sedimentary petrography. D. Appleton-Century Co., New York, 549 p.

REED, R. D., 1924, Some methods of heavy mineral investigation: Econ. Geology, v. 19, p. 320–337.

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FIGS. 1–4, MARCH, 1958

CYCLIC DEPOSITION IN THE JURASSIC CARMEL FORMATION OF EASTERN UTAH[1]

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ABSTRACT

The Carmel Formation, a marginal marine deposit of fine clastics and gypsum, exhibits cyclic deposition in eastern Utah. The cycles are well developed and consist of three divisions: a lower reduced unit of shales, siltstones, and platy limestones, an oxidized middle member of silty shale, and a top member of irregularly bedded gypsum. The probable cause of the cycles is a slow regression of the sea combined with minor periodic advances. Climatic changes are proposed as the mechanism for the readvances of the sea. The Carmel cycles are compared with somewhat similar deposits within the Moenkopi Formation in Arizona.

INTRODUCTION

While engaged in field work in eastern Utah during the summer of 1956, an interesting cyclic arrangement of sediments was studied in the Carmel Formation. These deposits are unique in that the cycles occur in an evaporite sequence, are well developed, numerous, and are found in several widely separated areas. In addition, the author has been unable to obtain much literature that describes similiar deposits.

The chief objective of this paper is to acquaint geologists with these cyclic deposits and their environmental implications, in the hope that deposits of similiar nature will be noted and described.

STRATIGRAPHY AND INTERPRETED GEOLOGIC SETTING

The Carmel Formation is one of a group of Mesozoic formations deposited in an environment characterized by arid and semi-arid conditions on a terrain of generally low relief in and adjacent to a shallow sea. This was probably the eastern margin of the Triassic-Jurassic geosyncline. The Navajo, Entrada, Curtis, and Summerville are adjacent formations deposited under environmental conditions similiar to those of the Carmel (fig. 1). They are typical marginal marine sediments within which lithologic variations perpendicular to the strandline can be easily discerned.

The Carmel Formation is particularly interesting in its lithologic variations. In the Wasatch Plateau, the Twin Creek Formation, a shallow marine deposit of platy-bedded, oolitic, fossiliferous limestones, is the Carmel equivalent. Eastward, sediments of Carmel age can be traced, grading first into dominantly shale and gypsum deposits, then a thin shale and siltstone sequence near the Utah-Colorado border, and finally pinching out completely in parts of western Colorado.

The eastern margin of the Jurassic sea

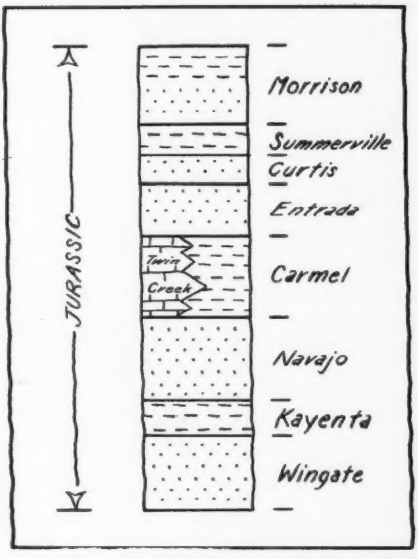

FIG. 1.—General stratigraphic section of Jurassic, Colorado Plateau.

[1] Published with the permission of the Chief Geologist, Standard Oil Company of California. Manuscript received September 1, 1957.

was probably not static during Carmel time. Rather, after the inundation that deposited shallow marine sediments as far east as the Colorado River area of Utah there was a slow withdrawal of the sea to the west. This gradual retreat, coupled with many minor readvances, appears to have been the mechanism causing deposition of the cyclic deposits herein described.

DESCRIPTION OF CYCLES

Well-developed cycles were measured at three sections: San Rafael River and Red Plateau in the San Rafael Swell and Sheep Creek Cap on the northern flank of the Uinta Mountains (fig. 2). In addition, less well-developed cycles were observed on the Muddy River in the southern part of the San Rafael Swell and Whiterocks Creek west of Vernal on the south side of the Uinta Mountains.

A complete arid cycle consists of three distinct lithologic divisions. The lowest unit, comprising ½ to ⅔ of the total cycle, is a gray-green, platy-bedded shale. Interbedded with this shale are a few flaggy siltstone and

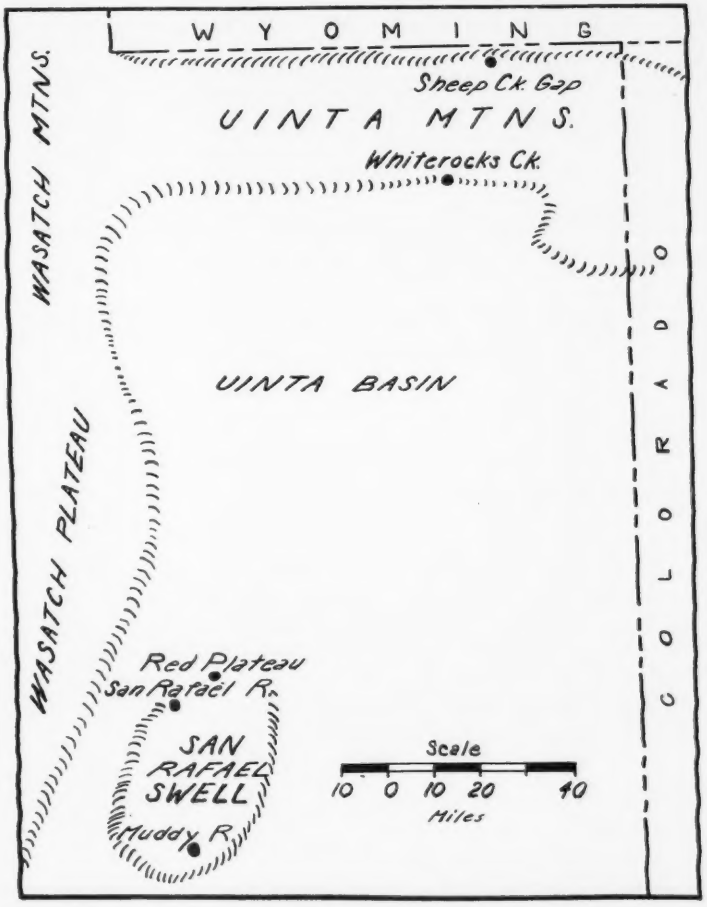

FIG. 2.—Map of Uinta Basin area with measured section locations.

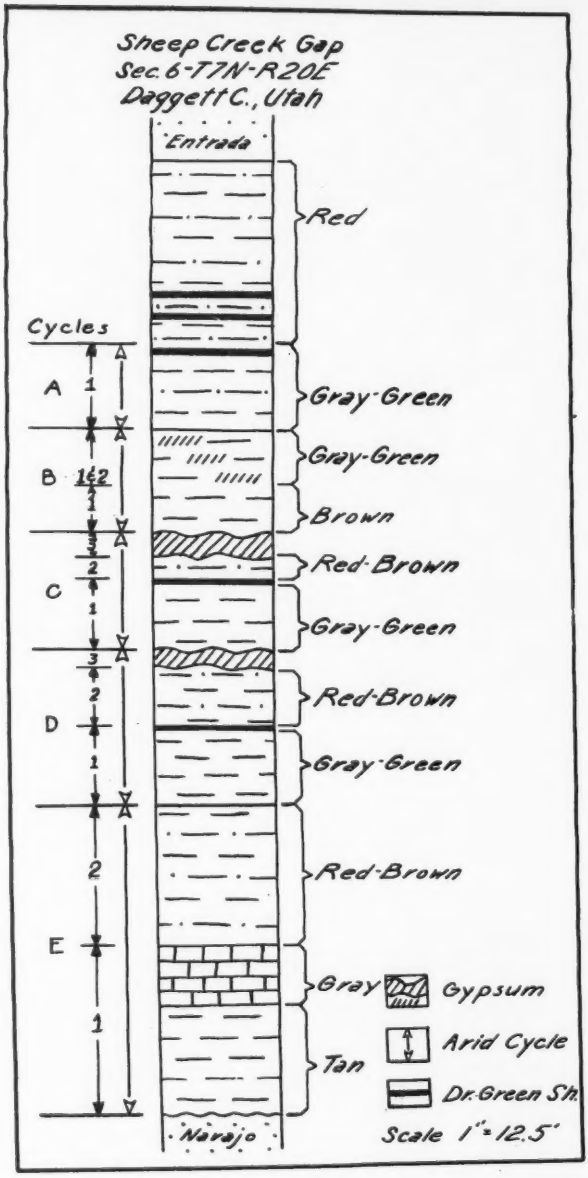

FIG. 3.—Section of the Carmel Formation showing Arid Cycles.

platy oolitic limestone beds. Oscillation or current ripple marks are common on bedding planes of the siltstones. The lowest unit is capped by a dark green shale band several inches thick. The middle unit, generally less than $\frac{1}{3}$ of the total cycle, is a red-brown, platy- to papery-bedded silty shale, frequently riddled with secondary cross-fiber gypsum veins. The top unit is gypsum that is generally white but may have a pale red or green coloration. It occurs in flaggy to slabby, contorted beds containing some intercalated silt-size clastics. Figure 3 is a representative section of the Carmel Formation showing the development of arid cycles. The cycles are lettered "A" to "E" on the left side of the column. Each cycle is in turn broken down into divisions represented by the numbers 1, 2, and 3, corresponding to the three lithologic divisions of the cycle: shale-siltstone, silty shale, and gypsum, respectively. The color breakdown of each of the cycles is shown on the right side of the column. Lithologic symbols used are conventional except where noted on the figure. Cycles "C" and "D" are complete and most nearly approximate the "ideal" sequence as outlined above.

The shale division, number 1, is best developed in cycle "E," and is represented by tan shale and gray limestone. This cycle, without the number 3 or gypsum sequence, is incomplete and probably represents dominantly deposition in a shallow, fine-clastic marine environment. The limestone contains oolites and a few shell fragments while bedding planes of thin siltstone beds are ripple marked. No green shale band is present at the top of the sequence.

Division 2, the red-brown siltstone sequence, is a very common type of lithology in the Triassic-Jurassic geologic column. It is best represented in cycles "C" and "D" and probably represents a shallow marine or mudflat type environment. From division 1 to division 2 there was a decrease in water depth and increase in clastic content, apparently as a result of closer proximity to the strand.

Gypsum, called division 3, is perfectly represented only in cycles "C" and "D." However, a little intercalated gypsum is also present in cycle "B." The scarcity of this evaporite in comparison to the other two types of lithology is not unusual considering that the gypsum beds probably represent marine deposition in a shallow, restricted arm of the sea where little influx of fresh waters could occur. Such a deposit calls for particularly specific conditions and a delicate balance of the environment. Water depth continued to decrease from division 2 to 3. In addition, influx of meteoric waters decreased, and restricted conditions prevailed.

Within the Carmel sections studied, basal cycles are generally the thickest. Progressively toward the top, cycles exhibit a decrease in thickness from a maximum of about 225 feet to less than 10 feet. Proportions of individual units generally remain the same with a possible decrease in gray shale percentage near the top.

CAUSES OF CYCLIC DEPOSITS

It is postulated that a major regression, due to basinal filling, may have caused the lithologic changes within each cycle. Shoaling of waters caused an excess of evaporation of sea water and resulted in increased salinity near the margins of the sea. Gray-green shale and oolitic limestone were probably deposited in a reducing environment into which little coarser clastic material was carried. Winnowing and redistribution of bottom materials by wave and current action tended to carry fine clays into off-shore zones where reducing conditions predominated. As filling continued, the strandline appears to have migrated slowly seaward. Gray-green shales thus grade vertically into oxidized near-shore red-brown silty shales. Similiarly, these gray shales may grade laterally into oxidized sediments (fig. 4). As a result of increased salinity, evaporite was deposited on top of siltstones. The cycle was completed by a minor readvance of the sea and return to reducing conditions.

The thin, intensely green shale beds may be the result of either reducing conditions caused by the accumulation of organic material or the result of ground water action. I favor the former, because there does not appear to be any lithologic evidence for ground water reduction always at the same stratigraphic position. Rather, the green shale band is always located just below oxidized sediments at the position where hypersaline conditions probably began to be dominant. An increase in salinity would cause the ex-

termination of stenohaline marine organisms living in the area and may have resulted in a reduced band, always at about the same stratigraphic position. The "more marine" conditions of division 1, cycle "E" may explain why there was no green band developed—the increase in salinity necessary for destruction of organisms did not occur.

Lack of calcium carbonate deposition as the dominant chemical sediment may be explained by the absence of carbonate ions in any significant amount in the marginal waters of the Carmel sea. The shelf on which the Carmel sediments were deposited was fairly level and covered by shallow waters. It is theorized that most of the carbonate was deposited farther west as the Twin Creek Formation. As a result of restricted circulation on the shallow shelf area, little new carbonate could be introduced to the area favorable for hypersaline conditions.

Between early Carmel time and Entrada time there was a general regression of the sea which culminated in the fluvial sandstone deposition of the Entrada Formation. It appears that this general regression accounts for the decrease in thickness of succeeding cycles. In any particular section, with each pulse represented by a lithologic cycle, the strand moved closer to the actual site of deposition. Current and wave action redistributed most sediments into deeper water. At the same time, minor fluctuations due to basinal filling became increasingly effective in stopping deposition at any particular site, resulting in thinner and thinner cycles. Finally, littoral conditions predominated, with resulting oxidized silty shale sediments of continental and brackish water environment. Figure 4 illustrates this interpretation.

MECHANISM OF MINOR TRANSGRESSIONS

The general cause of Carmel cyclic deposits, as outlined in the previous section, is based on field observations with detailed stratigraphic information, but the theory presented to explain these cyclic deposits requires a minor transgression as the initial step in each cycle. An explanation of the necessary mechanism is difficult to resolve. The major problem then is what force or forces caused each of these pulses? Below are listed some major reasons presented in the past by various authors for cyclic de-

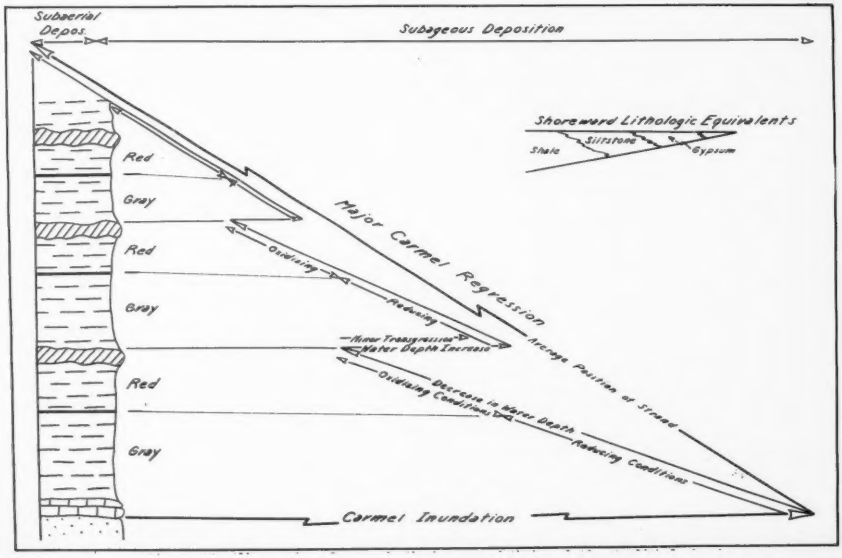

FIG. 4.—Diagrammatic illustration of water depth changes and their relation to lithologic changes.

posits (most pertaining to the late Paleozoic).

1. Climatic changes (Gignoux, 1950).
2. Compaction (Heide, 1950).
3. Mild positive and negative diastrophic movements (Weller, 1930).
4. Glaciation (Wanless and Shepard, 1955).
5. Periodic volcanism (Pettijohn, 1949).
6. Cyclic shift of delta distributaries (Pettijohn, 1949).
7. Major diastrophism at distance from cycles (Fairbridge, 1954).

From the above list, the following can be immediately eliminated: (2) compaction was not a factor in thin sequences as exemplified by Carmel cycles; (4) no glaciation is known to have occurred during Jurassic time anywhere in the world; (5) evidence of volcanism does not appear until Summerville time, as indicated by the presence of a few bentonite beds in this formation and numerous bentonite shales in the overlying Morrison beds; (6) the environment of deposition of Carmel cyclic deposits was probably not deltaic.

Minor regressions of the Carmel cycles apparently occurred fairly regularly, thickness depending on distance from the strand rather than time involved. We thus require a mechanism that is periodical in its actions. Three possible causes present themselves: (1) climatic changes; (3) mild positive and negative diastrophic movements; (7) major diastrophism at a distance from cycles. In addition, minor epirogenetic changes as the result of basinal filling and depression of the shoreline, may be a cause. I consider that while numbers (3) and (7) may be this rhythmic, either minor epirogenetic movements or particularly climatic changes related to the periodicity of earth rotation and axis translation seem more acceptable. Proof of the cause of cyclic sedimentation, however, must await the compilation of considerably more scientific information.

OTHER OCCURRENCES OF ARID CYCLIC DEPOSITION

The only other occurrence of cyclic deposits similiar to those described in this paper are in the Triassic Moenkopi Formation of Arizona (McKee, 1954). Sections of the Moenkopi Formation published by McKee (p. 49–50) show gypsum beds associated with either red or gray sediments predominately rather than with both red and green sediments as in the Carmel Formation. Green shaly mudstone beds up to 5 feet thick are present within several redbed units in the evaporite series. These may be analogous to the dark green bands previously described from the Carmel.

The environment of deposition, lithologies, and paleogeography of the Moenkopi are very similiar to those of the Carmel. Similarities of gypsum and associated deposits between the two formations are thus probably due to conditions of deposition rather than coincidence. A detailed examination of Moenkopi sections with the Carmel cycles in mind may yield more similarities.

ACKNOWLEDGEMENTS

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REFERENCES

FAIRBRIDGE, R. W., 1954, Symposium delivered to Graduate School of Geology, University of Kansas, on the subject of major epirogenetic movements. Unpublished.

GIGNOUX, MAURICE, 1950, Sedimentation rythmique dans les plaines maritimes et aufond des mers: Acad. sci., Paris Comptes rendus 230, p. 695–698.

HEIDE, S. VAN DER, 1950, Compaction as a possible factor in upper Carboniferous rhythmic sedimentation: 18th Int. Geol. Cong., Great Britain, Rept. pt. 4, p. 38–45.

MCKEE, E. D., 1954, Stratigraphy and history of the Moenkopi Formation of Triassic age: Geol. Soc. America Memoir 61, 133 p.

PETTIJOHN, F. J., 1949, Sedimentary rocks. Harper and Brothers, New York. 526 p.

WANLESS, H. R., AND SHEPARD, F. P., 1935, Sea level; climatic changes related to late Paleozoic cycles: Geol. Soc. America, v. 47, p. 1177–1206.

WELLER, J. M., 1930, Cyclical sedimentation of the Pennsylvanian Period and its significance: Jour. Geology, v. 38, p. 97–135.

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FIGS. 1–11, MARCH, 1958

EVAPORITE FACIES[1]

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ABSTRACT

The lateral distribution of evaporite facies, thickness, and limestone/carbonate ratio can be used to reconstruct the paleogeography and mode of deposition of evaporite rocks. Distribution of the evaporite facies, developed theoretically for a hypothetical model basin from chemical data for the evaporation of seawater and for reflux equilibrium show that:

1.—The facies pattern is arcuate and convex about an inlet,

2.—The expected section is thickest where halite is deposited in the center of the basin near the edge of the influx tongue and thinnest where carbonate minerals are deposited around the edge of the basin,

3.—The limestone/carbonate ratio should be highest in the path of influx flow near the inlet where normal marine conditions project into the evaporite basin.

Facies analysis of the Upper Silurian Salina Formation in Michigan, Ontario, Ohio, and Pennsylvania indicate that

1.—The Michigan Basin and the Ohio-New York Basin were separate evaporite basins, connected across the Findley Arch through the Chatham Sag,

2.—The principal inlet to the salt basins was in the vicinity of Georgian Bay in Ontario, which connected the Michigan Basin with the Arctic seaway,

3.—A subsidiary channel flowed northward into the Michigan Basin through an inlet in the vicinity of Clinton, Michigan, connecting the basin with the southern Appalachian seaway principally during middle Salina time,

4.—A persistent river flowed eastward into the Michigan Basin in the vicinity of Ludington, Michigan.

INTRODUCTION

Most evaporite minerals are deposited in marine or semi-marine basins where brine circulation between the open ocean and the basin is restricted by static and dynamic barriers (Scruton, 1953, p. 2503). Evaporation from the surface of the brine exceeds rainfall and terrestrial run-off in the basin, and the evaporation loss is balanced by influx of ocean brine. Thick deposits of anhydrite and salt necessitate continuous influx of ocean brine into the evaporite basin through the principal inlets, such as visualized by King (1947) and Scruton (1953, p. 2503–2507). The influx brine flows on the surface of the basinal brine from the inlet toward the distal end of the evaporite basin, during which evaporation increases the concentration of dissolved salts in the influx layer from the inlet basinward. Increased concentration and density of the influx waters are accompanied by mineral precipitation in the sequence discovered experimentally by Usiglio (1849, p. 92, 172), which is recorded in the modified form in table 1. The mineral sequence: *dolomite-anhydrite-halite* has been repeatedly recorded in descriptions of evaporite deposits (Sloss, 1953, p. 153).

One can calculate hypothetical patterns of evaporite deposition from Usiglio's data from the evaporation of sea water, provided the data are recast in terms of weights of minerals precipitated during the evaporation of a unit volume of brine (table 1). The thickness of minerals precipitated can be calculated for any postulated condition of brine density and rate of evaporation of brine by converting grams to volume, which is numerically equivalent to thickness on a unit area of the sea floor (fig. 1). As an example I have calculated the minerals precipitated during evaporation of one milliliter of brine having a density 1.1264 (table 1):

Mineral Phase	Weight in Grams	Thickness in Centimeters	Percent, Total Thickness
$CaCO_3$	0.963×10^{-3}	0.356×10^{-3}	8
$CaSO_4$	10.20×10^{-3}	4.420×10^{-3}	92
NaCl	0.0	0.0	0

Total thickness: 4.803×10^{-3} centimeters.

[1] Manuscript received April 19, 1957.

TABLE 1.—*Properties of the brine and weight of minerals precipitated from the evaporation of sea water*

Density	Volume	Salinity*	Minerals precipitated, grams $\times 10^{-3}$ per milliliter of brine evaporated		
			$CaCO_3$	$CaSO_4$	NaCl
1.0258	1.000	37.5	—	—	—
1.050	0.533	68.5	0.137	—	—
1.084	0.316	111.9	tr	—	—
1.1037	0.245	141.0	tr	—	—
1.1264	0.190	157.1	0.963	10.20	—
1.1604	0.1445	222.5	—	15.80	—
1.1732	0.131	240.5	—	13.62	—
1.2015	0.112	274.0	—	8.42	—
1.2138	0.095	291.0	—	2.99	192
1.2212	0.064	305.2	—	4.76	312
1.2363	0.039	325.7	—	2.80	316
1.2570	0.030	339.5	—	1.64	298
1.2778	0.023	357.5	—	—	315
1.3069	0.016	399.0	—	—	207

(Modified from Clarke (1924) and Briggs (1957).)

* Salinity is calculated as the weight proportion of the dissolved solids per kilogram of brine having the density shown in the left-hand column.

This method has been applied to an analysis of anhydrite-dolomite laminae of the Castile Formation (Briggs, 1957). In the present paper I have constructed the theoretical distribution of evaporite minerals in an ideal basin in order to evaluate the meaningful interpretive characters of an evaporite pattern. These characters are then used to interpret the evaporite facies of the Upper Silurian Salina Formation of the Michigan and Ohio-New York Basins in terms of their paleogeography.

HYPOTHETICAL EVAPORITE DEPOSITIONAL FACIES

If, as in the example above, each position on the surface of a marine evaporite basin has its own *particular* value of brine density,[2] then at each position a *particular* mineral or combination of minerals will precipitate by evaporation (table 1). Like precipitates having equal thicknesses will form in positions having like densities. Under conditions of continuous influx of brine into the basin, fresher low-density brine near the inlet may precipitate carbonate minerals while saline high-density brine at the distal end of the basin is precipitating anhydrite and halite. Such is the premise upon which the hypothetical distribution of evaporite facies is founded.

In order to more exactly define the mineral distribution produced by evaporation of sea water, I have constructed a hypothetical

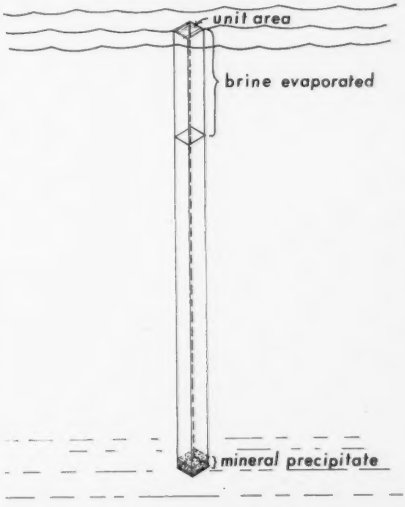

FIG. 1.—Diagrammatic illustration of the method of calculating the thickness of minerals precipitated by evaporation of a given thickness of brine over a unit area of the evaporite basin.

[2] Actually salt concentration or salinity. Since temperature effects are small, brine density is used in place of salinity, as Usiglio's data are expressed in that form.

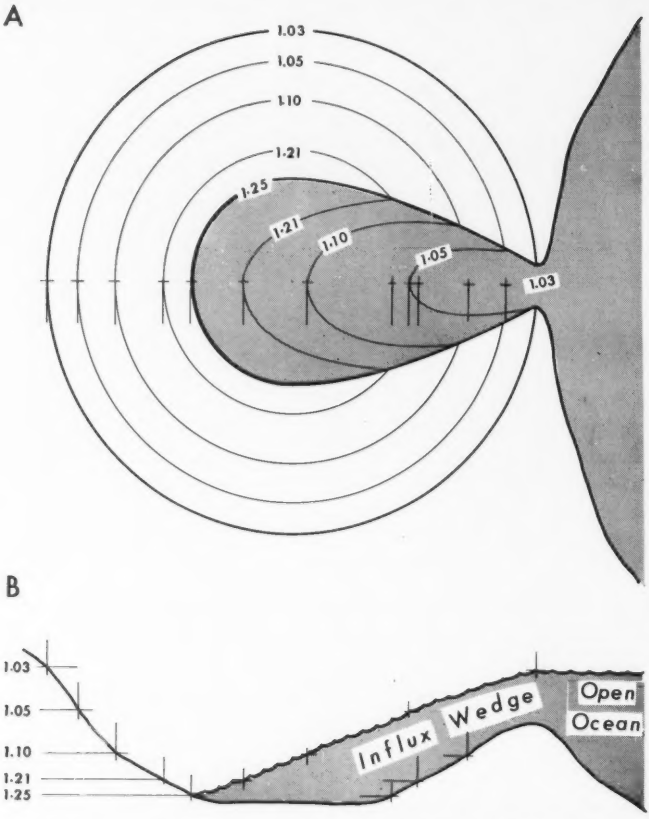

FIG. 2.—Geometry of the model evaporite basin at a stage of saline equilibrium in plan view (A) and in cross-section (B).

TABLE 2.—*Calculations of evaporite mineral deposition in the model evaporite basin*

Density Range	Mineral Deposition									Total Thickness (units)*
	Calcite			Anhydrite			Halite			
	g/cm²	cm/cm²	%	g/cm²	cm/cm²	%	g/cm²	cm/cm²	%	
Inlet End of Basin:										
1.03–1.10 (o-a)	137	51	100	0	0	0	0	0	0	51
1.10–1.13 (a-b)	963	356	8	10,200	4,420	92	0	0	0	4,805
1.13–1.21 (b-c)	0	0	0	40,830	17,750	17	192,000	88,500	83	106,250
1.21–1.25 (c-d)	0	0	0	9,200	4,000	1	926,000	427,000	99	431,000
Distal End of Basin:										
1.03–1.10 (h-g)	137	51	100	0	0	0	0	0	0	51
1.10–1.13 (g-f)	1,100	407	8	10,200	4,420	92	0	0	0	4,827
1.13–1.21 (f-e)	1,100	407	0	51,030	22,200	20	192,000	88,500	80	111,107
1.21–1.25 (e-d)	1,100	407	0	60,230	26,200	5	1,118,000	515,000	95	541,607

* Thickness is in units: cm $\times 10^{-4}$/ml evaporated.

model evaporite basin in which the lines of equal brine density on the surface of the basin are simple arcs concave to the inlet (fig. 2). The density levels in the model basin correspond to the relative volumes of the partially evaporated brine (table 1). The noticeable decrease in level of the water's surface between the inlet and the distal edge of the basin is produced by evaporation and reduction of volume, since the volume of brine having a density of 1.257 is only 3 percent of that having a density 1.0258. A like slope occurs in natural evaporation basins, such as San Diego Bay, California (Scruton, 1953, p. 2500–2501). The type and thickness of mineral deposition between lines of equal density can be determined by calculating the contribution on a unit area and integrating this over the area between the lines of equal density. The calculations for the model evaporite basin are summarized in table 2.

The calculated mineral compositions for the model basin are plotted in figure 3, and the pattern of mineral deposition is shown in figure 4. From the sequence of mineral precipitation and from the distribution of the mineral patterns, one can establish several criteria for the interpretation of evaporite patterns based upon percent-thickness maps:

1.—The sequence of mineral deposition, carbonate→anhydrite→halite (C→A→H on the ACH diagram), duplicates the facies pattern from the inlet and edges of the basin toward the center. The pattern and boundaries between patterns on the ACH diagram used for analysis of evaporite basins should be consistent with the sequence.

2.—The evaporite pattern, in the simplified hypothetical case presented, is arcurate about an inlet, the convex side being toward the inlet.

Thickness is a valuable interpretive tool also. The evaporites are thickest in the center of the basin where halite precipitates and thinnest around the edges where carbonate precipitates. Although there is relatively little carbonate mineral precipitation owing to evaporation, there will be a substantially thicker accumulation of normal marine limestones than that calculated in the inlet areas where the normal marine environment projects into the evaporite basin (Sloss, 1953). Furthermore, if high

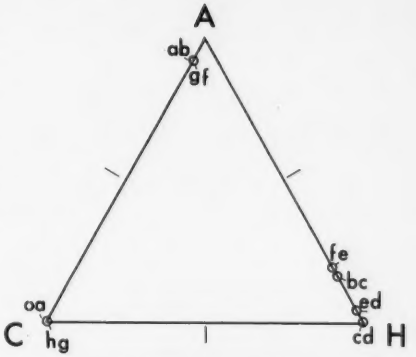

FIG. 3.—An ACH-diagram showing the sequence of evaporite mineral deposition for the model evaporite basin from the inlet channel to the edge of the inlet wedge (o-a-b-c-d) and from the distal edge of the basin to the inlet wedge (h-g-f-c-d). C = carbonate, A = anhydrite, H = halite. Data are from table 2.

salinity promotes the growth of dolomite over calcite as a carbonate mineral, as it theoretically should, then limestone will be more abundant in the inlet and nearby areas, and dolomite, elsewhere.

The thickness of evaporite minerals deposited in the inlet and distal ends of the basin (table 2) were calculated for the period necessary to establish saline conditions; moreover, with continued saline equilibrium, evaporite minerals will continue to precipitate from the inlet tongue, but not beyond it. Thus, a complete evaporite cycle should be very thick in the saline regions of the influx tongue and relatively thin elsewhere. Even though the type, relative abundance, and distribution of evaporite minerals in natural deposits can be best explained in terms of influx equilibrium, other features, especially the typical lamination of evaporite rocks, suggest periodic refreshening (Udden, 1924; Lang, 1950; Briggs and Lucas, 1954; Briggs, 1957). Both influx equilibrium and periodic refreshening theoretically produce similar facies patterns, though the total possible thickness is greater for the process of continuous equilibrium.

During the flow of low-density influx brine over high-density basinal brine, mixing of the two fluids may occur at their interface (Scruton, 1953). When brines

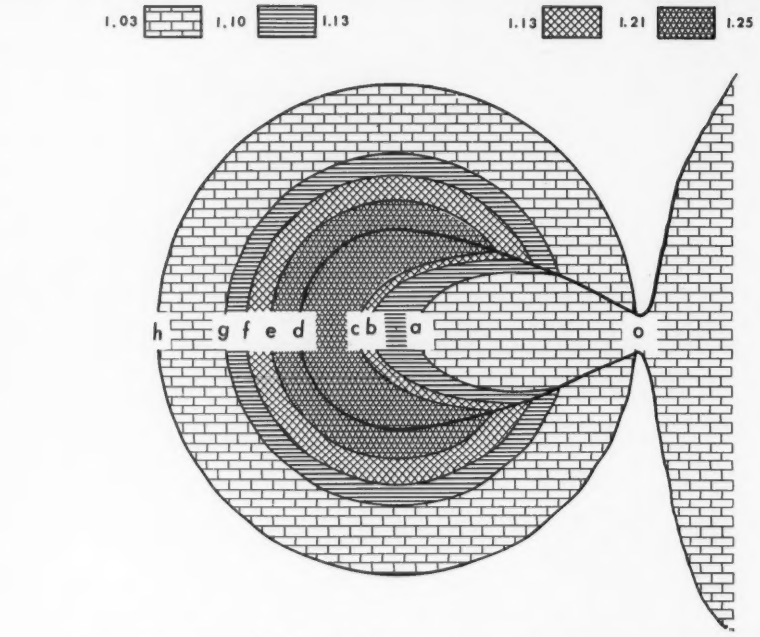

FIG. 4.—Map of evaporite facies developed in the model basin during the development of conditions of saline equilibrium. Data are from table 2.

representing different stages of concentration in the evaporative process are mixed, evaporite minerals will precipitate from the low-density brines whose concentrations are in excess of their solubility products in the mixed solution. For example, if influx brine of density 1.07, which is relatively rich in calcium-, carbonate-, and sulfate-ions, mixes with an equal volume of brine of density 1.25, which has been essentially depleted of these ions by evaporation and precipitation, approximately 40 percent of the sulfate-ions and all of the carbonate-ions will be removed from the influx brine by precipitation (table 1). Thus mixing could have an important effect on the depositional pattern, and the effect should be greatest in the channeled flow areas where high volume and velocity of influx promote mixing of solutions. The result is difficult to evaluate except qualitatively, but it seems to be relatively unimportant in the Salina evaporites.

Occasional rains upon the evaporite basin have little effect other than to stop the deposition of evaporite minerals until the rainfall layer is evaporated, since it adds little or no mineral matter and it cannot sink into the denser basinal brine. Terrestrial runoff will cause a much greater effect. Streams draining into the basin, even though intermittently, may carry considerable amounts of clastic and dissolved mineral load into the basin. An adjacent land area underlain by silicate rocks will contribute sand, silt, and clay mud to the evaporite basin. Owing to the high oxidation potential of the environment in and surrounding the basin (Krumbein and Garrels, 1952, p. 20), the sediments will most generally be red (Landes, 1945; Alling, 1928; Krumbein, 1951; Sloss, 1953). Where the terrain is composed of carbonate rocks as well, calcareous or dolomitic shales should be characteristic deposits especially near the mouths of streams. Streams draining dominantly carbonate terrains, such as in the Michigan Basin during the late Upper Silurian, should carry a high proportion of carbonate and sulfate ions and particles, and their deposits should be largely dolomite, anhydrite, and gypsum.

Where streams flow into the basin waters carbonate and sulfate minerals will precipitate in zones like those produced by an oceanic inlet. The position of an inflowing stream should be marked by a distinctly thinner sequence of evaporite deposits in the deltaic region because the terrestrial water dilutes the basinal brine. The particulate stream load should be recognizable in the presence of quartz, rounded carbonate grains, and oölites.

Size is not a distinctive character of evaporite basins. Salt pans utilized in the manufacture of solar salt occupy only a few acres whereas the Permian Castile Evaporite Basin is estimated by King (1947, p. 475) to have covered about ten thousand square miles. The Salina Basin occupied approximately 150,000 square miles during the late Upper Silurian. However, the surface area of the basin in part controls the cross-sectional dimensions of the brine in the inlet channel, since the net evaporation loss must be balanced by influx through the inlet channel. For the Salina sea the net annual evaporation loss is estimated to have been five feet (Briggs, 1957), thus the water loss from the Salina Basin was at the rate of 2.09×10^{13} cubic feet per year, or 6.61×10^{5} cubic feet per second. An equal volume of influx brine must have replaced this loss. To accommodate the volume of influx brine having a velocity of one foot per second, a channel averaging one hundred feet in depth need be only $1\frac{1}{4}$ miles wide, whereas a channel only 10 feet in depth need be 12 miles wide. These are conservative estimates since the assumed net evaporation rate is relatively low,[3] and the channel velocity is relatively high. But if the evaporation rate were doubled, or the channel velocity halved, the width need be only doubled. Widths of 5, 10, or 20 miles are relatively the same order of magnitude and are consistent with evaporite patterns of the Salina deposits and the precision with which they can be estimated.

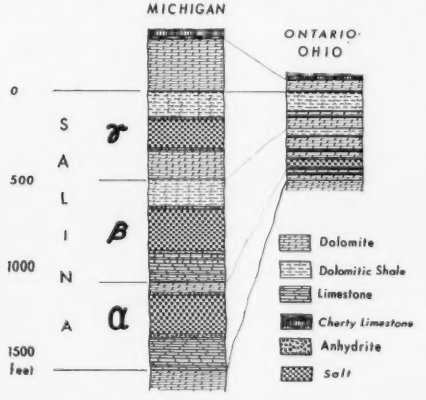

FIG. 5.—Generalized stratigraphic column of the Salina Formation in the Michigan basin and in the Ohio-New York Basin.

FIG. 6.—Plot of percent-thickness analyses of evaporites in the Salina Formation of Michigan, Ontario, Ohio, and Pennsylvania in terms of carbonate (C), anhydrite (A), and halite (H) on an ACH-diagram. Approximately 150 analyses of three evaporite units in 56 wells are represented.

THE SALINA FORMATION

The theory can be tested in the relative abundance of each evaporite rock and their regional variation in a natural evaporite deposit. For the Salina Formation, I have expressed relative abundance of each major evaporite rock as percent total thickness of the Salina evaporites, and have shown the lateral variation by means of a facies map. Drilling chips mounted on strip logs from the Subsurface Laboratory of the University of Michigan were used to visually estimate the proportions of halite, anhydrite (or gypsum) and carbonate rock in each of 56 wells that penetrated the Salina Formation in Michigan, Ontario, Ohio and Pennsylvania.

[3] King (1947, p. 475) estimated the annual rate of evaporation from the Castile Sea to have been 9.5 feet.

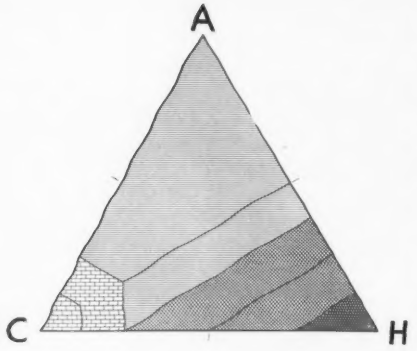

FIG. 7.—Patterns used to represent analyses of evaporite rocks in the Salina Formation.

Three major evaporite cycles (Sloss, 1953, p. 153) can be recognized in the subsurface Salina in the Michigan Basin (fig. 5). Not all of these lithologic units occur in all the wells, nor is such to be expected (fig. 4). In the Ohio-New York Basin the Salina section differs considerably from that in the Michigan Basin, but the evaporite rocks in the two basins can best be correlated by means of the middle evaporite unit. Fortunately, the sections that are most difficult to correlate are those made up essentially of dolomite alone, and the composition of any part of the section does not vary much from that of the whole section. Such facies are not significantly variant. The well sections that show the most variation are most significant in facies analysis, and these are readily correlated in subsurface.

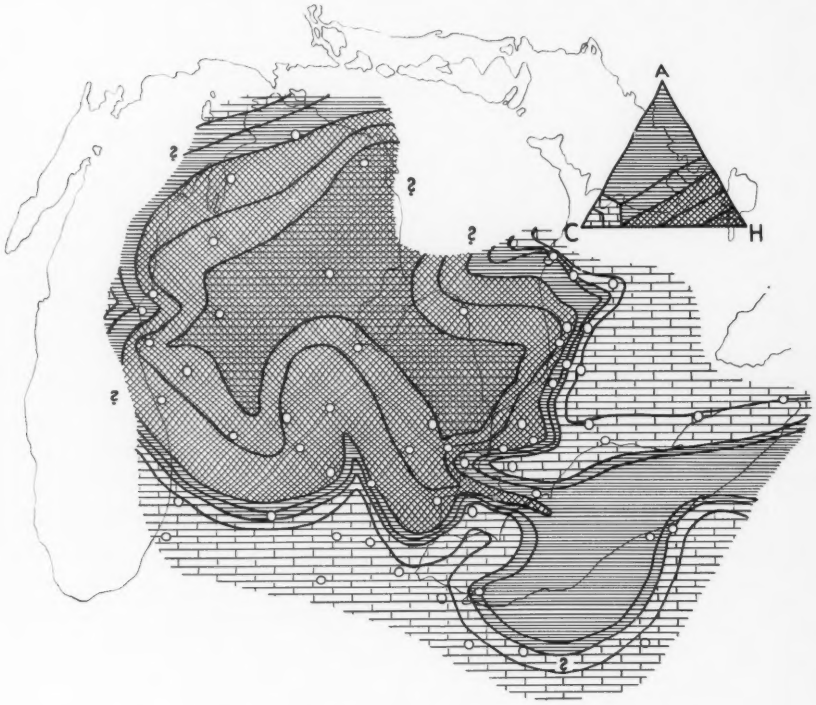

FIG. 8.—Evaporite facies map of Salina evaporites in the Michigan Basin and in the Ohio-New York Basin.

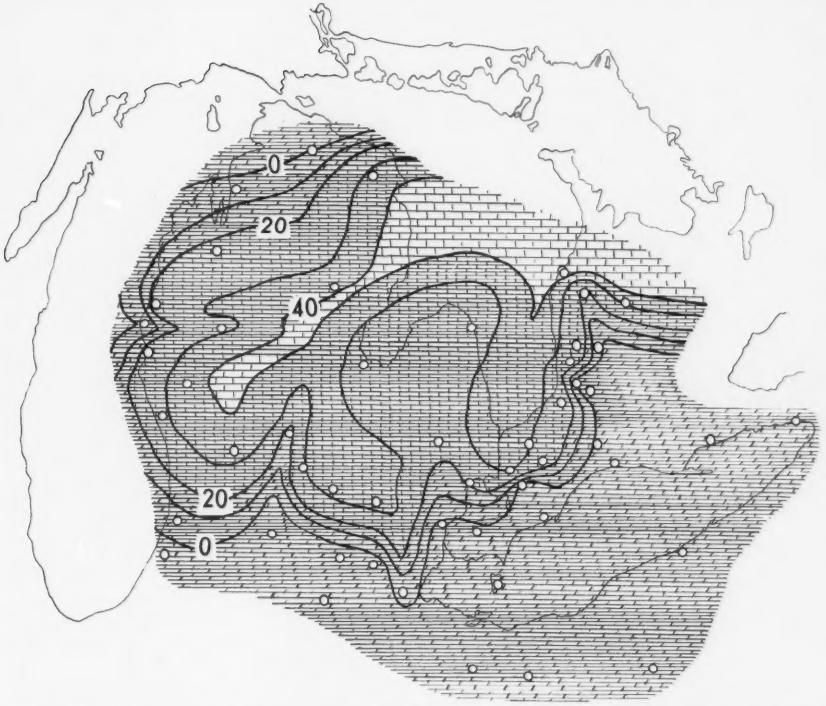

FIG. 9.—Map showing the distribution of limestone/carbonate percent in evaporite rocks of the Salina Formation of the Michigan Basin and the Ohio-New York Basin.

The results of approximately 150 analyses of Salina rocks, the total formation and each major evaporite unit of the formation in the subsurface throughout most of the basin, are shown in figure 6 on an ACH-diagram. The concentration of analyses in the lower third of the field, and the theoretical path of evaporite mineral crystallization (fig. 3) support the idea that the four-fold subdivision of the ACH-diagram shown in figure 7 represents the simplest yet the most significant genetic differences in compositional variation for rocks in the Salina Formation.

The analysis of the Salina Formation is shown on the facies map in figure 8. The map differentiates clearly the evaporite basin in Michigan and western Ontario from the correlative basin in Ohio, Pennsylvania, and New York. The Michigan Basin was relatively the more saline. The interconnecting passage between the basins is shown to cross southwestern Ontario in the vicinity of Chatham. Three inlets fed the basins from Georgian Bay, Ontario; Clinton, Michigan; and Ludington, Michigan. The limestone/carbonate ratio (fig. 9) clearly demonstrates the Georgian inlet to be the principal connection to the open ocean during the entire span of Salina time. The Clinton inlet apparently fed the influx brine into the Michigan Basin principally during deposition of the middle part of the Salina, for the highest limestone/carbonate ratios and the thickest total limestone occur in the carbonate rocks at the base of the middle evaporite unit. Such is suggested by the broad area between 30–40 percent isopleths in south-central Michigan (fig. 9). The Ludington inlet most likely represents the average position of the major stream. It is characterized by low salinity (fig. 8), low limestone/carbonate ratio (fig. 9) and low thick-

ness (fig. 10). It is an amazingly persistent feature for all units of the Salina and the overlying Bass Island.

The physical barrier between the Michigan and Ohio-New York Basins is a northeast-southwest trending positive ridge, commonly identified as the Findlay Arch. The carbonate facies, low limestone/carbonate ratio, and relative thinness support this premise. These features suggest carbonate reef structures along the crest and flanks of the arch, which have been found in the late Guelph or early Salina carbonates of this region (Roliff, 1949, p. 166). The Ohio-New York Basin was apparently supplied relatively fresh brine from the Georgian inlet, since the limestone/carbonate ratio is relatively high along a channel through the Michigan Basin that joins the Georgian inlet and the Chatham pass (Roliff, 1949, p. 166, fig. 8). The Georgian inlet appears to have connected the evaporite basins with the seaway that traversed Canada into the Arctic region (Kay, 1942; Swartz et al., 1942; Lowenstam, 1950; Schuchert, 1955). Either land areas or reef structures prevented ingress of seawater at other places in Ontario and across northern New York state. The Clinton inlet probably joined with the seaway in the southern Appalachian region. I have no knowledge of the type of marginal barrier between the Ohio-New York Evaporite Basin and the open ocean to the south during periods of high salinity in the basin; I assume the barrier to be reef structures. Since the Salina-equivalent section thickens southward in north-central Ohio and becomes more argillaceous,

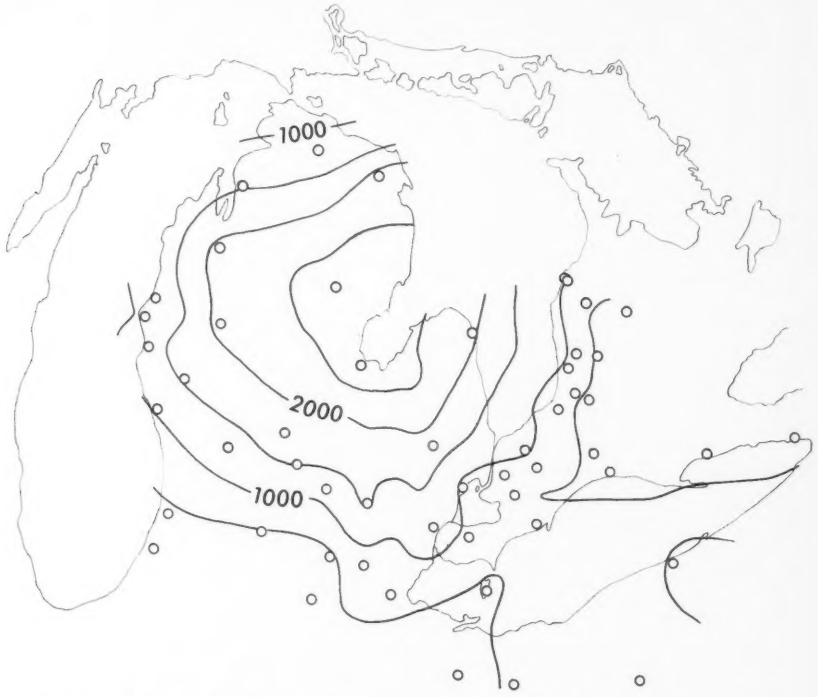

FIG. 10.—Map showing the total thickness (feet) of rocks in the Salina Formation in the Michigan Basin and in the Ohio-New York area.

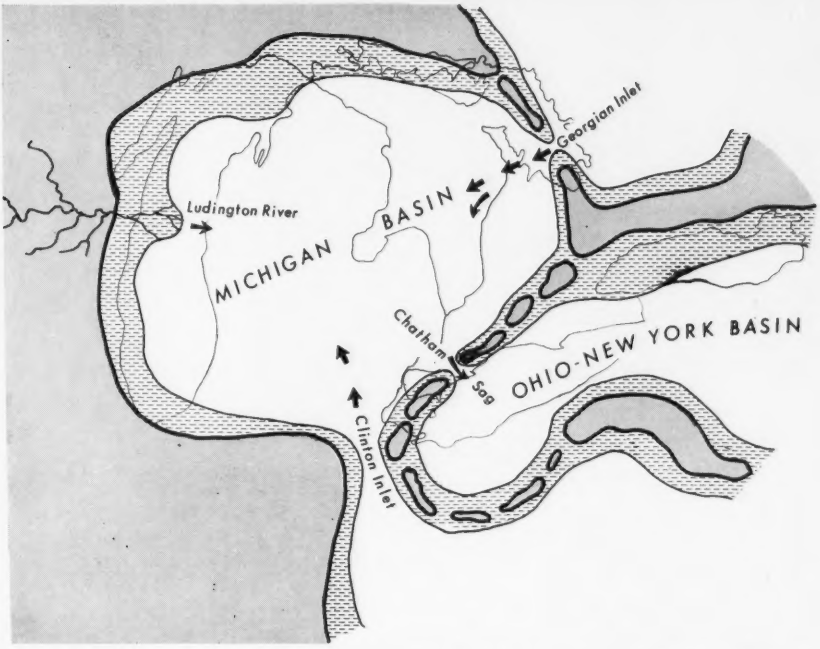

FIG. 11.—Paleogeographic map of the Michigan Basin and the Ohio-New York Basin during Salina time, based on analyses of evaporite facies, limestone/carbonate percentages, and total thickness.

the evaporite facies pattern becomes less meaningful in that region. These features are shown on a paleogeographic map which represents a composite picture of the Salina seas during times of high salinity (fig. 11).

The Salina time was not represented entirely by saline conditions. Thick fossiliferous limestones at the base of the lower and middle evaporite units record periods of free circulation of open marine waters of normal salinity between the Arctic seaway into Ohio, Kentucky and the Appalachian trough. Indeed, when one considers the high rate of evaporite mineral deposition,[4] one realizes that the 2500 feet of evaporites in the center of the Michigan Basin represent but a small part of Salina time. The limestones and open seaways may be more representative of the normal conditions of the Late Upper Silurian in this region.

[4] Halite can accumulate faster than ¾ foot per year under optimum conditions.

ACKNOWLEDGMENTS

The studies of evaporite rocks in the Michigan Basin have been supported by research grants from the Horace H. Rackham School of Graduate Studies, University of Michigan. I am indebted to my colleagues for their constructive discussions of evaporite deposition, in particular to J. A. Dorr, D. F. Eschman, L. F. Dellwig, P. T. Lucas, and James Boudouris. I owe special thanks to James Boudouris for his analyses of 25 wells in Michigan which are used in this report. The manuscript was critically read by K. K. Landes who suggested several important improvements.

REFERENCES

ALLING, H. L., 1928, The geology and origin of the Silurian salt of New York state: New York State Mus. Bull. 275, 139 p.

BRIGGS, L. I., 1957, Quantitative aspects of evaporite deposition: Michigan Acad. Sci. Papers (in press).

BRIGGS, L. I., AND LUCAS, P. T., 1954, Mechanism of Salina salt deposition in the Michigan Basin (Abstract): Geol. Soc. America Bull., v. 65, p. 1233.

CLARKE, F. W., 1924, Data of geochemistry: U. S. Geol. Survey Bull. 770, p. 218–260.

KAY, G. M., 1942, Development of the northern Allegheny synclinorium and adjoining regions: Geol. Soc. America Bull., v. 53, p. 1601–1658.

KING, R. H., 1947, Sedimentation in the Permian Castile Sea: Am. Assoc. Petroleum Geologists Bull., v. 31, p. 470–477.

KRUMBEIN, W. C., 1951, Occurrence and lithologic associations of evaporites in the United States: Jour. Sedimentary Petrology, v. 21, p. 63–81.

KRUMBEIN, W. C., AND GARRELS, R. M., 1952, Origin and classification of chemical sediments in terms of pH and oxidation-reduction potentials: Jour. Geology, v. 60, p. 1–33.

LANDES, K. K., 1945, The Salina and Bass Island rocks in the Michigan Basin: U. S. Geol. Survey Oil and Gas Investigations, Prelim. Map 40.

LANG, W. B., 1950, Comparison of the cyclic deposits of the Castile and Salado Formations of the Southwest: Geol. Soc. America Bull., v. 61, p. 1479–1480.

LOWENSTAM, H. A., 1950, Niagaran reefs of the Great Lakes area: Jour. Geology, v. 58, p. 430–487.

ROLIFF, W. A., 1949, Salina-Guelph fields of southwestern Ontario: Am. Assoc. Petroleum Geologists Bull., v. 33, p. 153–188.

SCHUCHERT, C., 1955, Atlas of paleogeographic maps of North America. Wiley and Sons, New York. 177 p.

SCRUTON, P. C., 1953, Deposition of evaporites: Am. Assoc. Petroleum Geologists Bull., v. 37, p. 2498–2512.

SLOSS, L. L., 1953, Significance of evaporites: Jour. Sedimentary Petrology, v. 23, p. 143–161.

SWARTZ, C. K., *et. al.*, 1942, Correlation of the Silurian formations of North America: Geol. Soc. America Bull., v. 53, p. 533–538.

UDDEN, J. A., 1924, Laminated anhydrite in Texas: Geol. Soc. America Bull., v. 35, p. 347–354.

USIGLIO, J., 1849, Concentration of sea water: Anal. Chem., (3), v. 27, p. 92, 172.

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FIGS. 1–5, MARCH, 1958

PETROLOGY OF THE WHITA SANDSTONE, SOUTHERN SCOTLAND[1]

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ABSTRACT

The Whita Sandstone at the base of the Carboniferous of Eastern Dumfriesshire and Western Roxburghshire of Southern Scotland is a homogeneous sandstone with respect to composition, shape, and size. Orientation, shape, and heavy mineral studies suggest a northerly source of material from the Southern Upland massif.

INTRODUCTION

The Whita Sandstone is a thick diachronous sandstone forming the base of the Cementstone Series of the Lower Carboniferous of Eskdale and Liddesdale in eastern Dumfriesshire and western Roxburghshire (Nairn, 1956; Garwood, 1931). The general geological relationships of the Whita Sandstone at the western end of its outcrop are shown in figure 1. It reaches a maximum thickness of 700 feet in Eskdale, where, above the town of Langholm, it was once extensively quarried. Four miles west of Eskdale the Whita Sandstone is absent.

The material forming the basis of this account was collected from the Whita Hill quarries, Langholm, and from the Tarras Water some three miles to the northeast. The absence of marker horizons and the diachronous nature of the sandstone make studies such as that of Allen (1948) impossible and the examination was concerned with provenance, vertical variation, and a comparison of the two areas collected.

PETROLOGY

Field Character

In the field the Whita Sandstone appears as a massive, white to grey, unfossiliferous sandstone. It is non-micaceous, and argillaceous material is absent although a few greenish siltstone partings occur. There are irregular calcareous bands and lenses occurring near the base, from which most of the carbonate has subsequently been leached. These calcareous bands are also iron-rich. Near the top of the sandstone several pebbly horizons occur in which there are pebbles of vein quartz with some white to grey sandstone fragments.

[1] This study was submitted as part of a Ph.D. thesis, University of Glasgow, 1954. Manuscript received May 8, 1957.

Thin Section

The sandstone falls into the orthoquartzitic group of Tallman (1949), Pettijohn (1949) and is a mature orthoquartzite according to Folk (1951). Apart from quartz only the felspars collectively and chert exceed 1 percent on a number frequency basis. The proportion of orthoclase present is roughly constant, although the proportions of microcline and sodic plagioclase are more variable, as is shown in tables 1 and 2 where the specimens are tabulated in a stratigraphical order. Rock fragments are rare, and only one doubtful greywacke fragment has been recorded. Occasional flakes of muscovite are found, often bent between quartz grains. Ilmenite and leucoxene grains are not uncommon. The cementing material is secondary silica as quartz overgrowths with some secondary limonite. In the calcareous samples the secondary silica pre-dates the calcareous matrix which corrodes both sand grains and secondary silica. In the calcareous samples, many grains have a thin limonitic coating.

Quartz grains with undulose extinction are common but always subordinate in number to the unstrained variety. Inclusions in quartz are apparently ubiquitous, and the descending order of frequency on Mackie's scale (1896) is invariably acicular, regular, irregular. The inclusions show considerable variety, rutile, tourmaline, zircon, magnetite, and muscovite all having been detected.

Chert grains of fine and coarse texture with transitional types are quite common, and increase in number upwards until the proportion exceeds the combined felspars. This appears to be due to an increase in the fine-textured grains (see tables 1 and 2) which replace the coarse-textured grains as

the commoner form. The fine-textured grains conform to the micro-crystalline quartz, and the coarse to the chalcedonic quartz of Folk and Weaver (1952). Both chert and acid igneous rocks according to Eckford and MacGregor (1948) form the ultimate source of the "quartz mosaics." In addition to this, "mosaics" of the chalcedonic variety have been detected as vesicular infillings in some of the lavas of the Birrenswark Volcanic Group which underlies the Whita Sandstone.

Chemical Analysis

The calcium, magnesium, and iron present in the calcareous samples was estimated by standard volumetric methods. The acid soluble fraction usually represented some 30–40 percent by weight of the total sample (table 1).

Heavy Mineral Analysis

Since the size distribution of heavy minerals differs from that of quartz (Rubey,

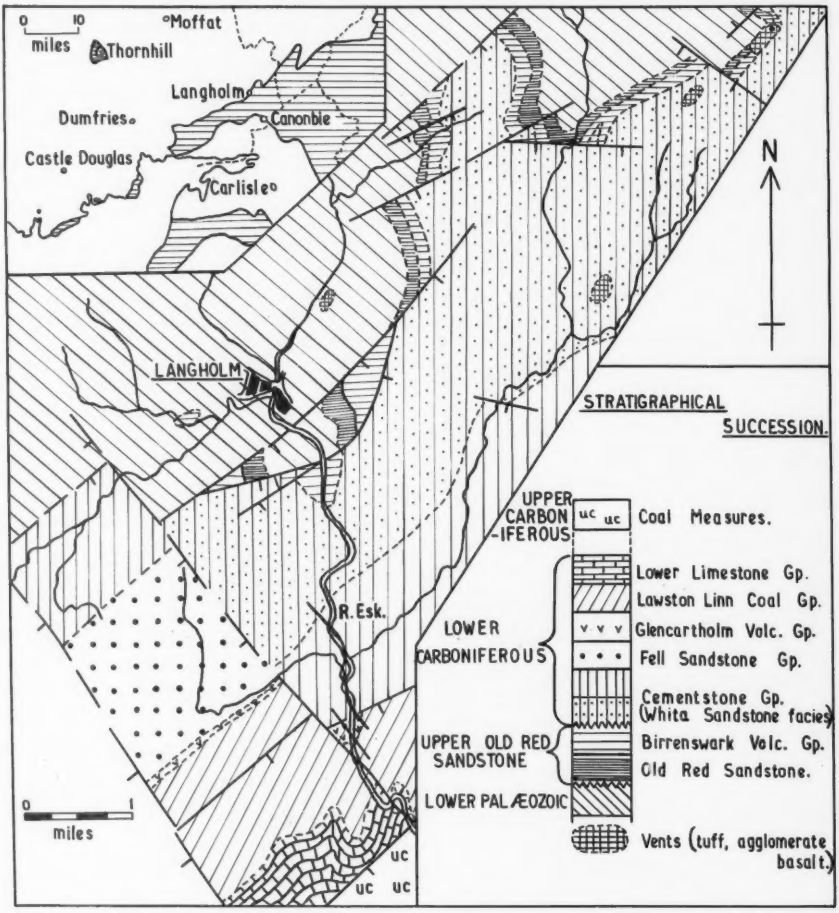


FIG. 1.—Geological map of the western end of the Whita Sandstone outcrop. The regional setting is indicated in the inset map.

TABLE 1.—*Whita Sandstone from Whita Hill.*

Specimen.	Column 1. Thin Section Analysis. Feldspar propn. plag.-microcline	Feldspar-mosaic propn.	Mosaic propn. fine-coarse	Column 2. Chemical Analysis. CaO%	MgO%	Column 3. Size Analysis. Q_{50}	Skewness	Kurtosis	Sorting. (Trask's coeff.)	Column 4. Shape Analysis. Roundness. ½Ø grade	Bø grade	Sphericity. ½Ø grade	Bø grade	Column 5. Orientation.
37	Pg > Mic	Qm > Flsp.	Qmf > Qmc			·300	·965	·205	1·277	·372	·393	·699	·669	W.
39	Mic > Pg	Qm > Flsp	Qmf > Qmc			·309	·986	·282	1·250	·379	·453	·697	·624	N–NNW.
40	Mic > Pg	Qm > Flsp	Qmf > Qmc			·450	·925	·312	1·118	·428	·446	·623	·669	NW.
41	Mic > Pg	Qm > Flsp	Qmf > Qmc			·295	·920	·224	1·456	·398	·374	·673	·666	N–NNE.
42a(calc)	Mic > Pg	Qm > Flsp	Qmf > Qmc	11·4	1·51	·380	·940	·280	1·288	·391	·400	·674	·671	
42 b						·375	1·001	·270	1·280	·370	·390	·675	·649	WSW.
43	Mic=Pg	Qm > Flsp	Qmf > Qmc			·380	·978	·273	1·243	·375	·408	·718	·646	
45 (calc)	Mic > Pg	Qm > Flsp	Qmf > Qmc	15·4	1·58	·245	·945	·212	1·221	·437	·446	·691	·649	N.
46	Mic > Pg	Qm > Flsp	Qmf > Qmc			·278	1·08	·230	1·310	·368	·423	·693	·681	
47a(calc)	Pg > Mic	Qm > Flsp	Qmc > Qmf	16·8	1·3	·338	·965	·265	1·280	·412	·420	·672	·653	N.
47c	Pg > Mic	Qm > Flsp	Qmc > Qmf							·396	·407	·713	·669	NNW.
48	Mic > Pg	Flsp > Qm	Qmc > Qmf			·410	·870	·276	1·241	·437	·404	·693	·664	N–NNE.
49	Mic > Pg	Flsp > Qm	Qmc > Qmf			·281	1·01	·262	1·233	·392	·433	·719	·669	N–NNW.
50(calc)	Mic > Pg	Qm > Flsp	Qmc > Qmf	10·8	1·67	·281	1·08	·195	1·241	·408	·416	·686	·641	N.
51	Mic > Pg	Flsp > Qm	Qmc > Qmf			·253	·930	·276	1·400	·404	·419	·689	·670	N.
53(calc)	Mic > Pg	Flsp > Qm	Qmf > Qmc	16·2	not estimated									
54	Mic > Pg	Flsp > Qm	Qmf > Qmc			·370	·890	·263	1·292	·400	·408	·682	·668	WNW.
55	Mic > Pg	Flsp > Qm	Qmc > Qmf											

1933a, 1933b), separations were made from whole samples. The yield from bromoform separations was small, averaging only .03 percent by weight. The mineral examination was mainly qualitative.

Two generations could be recognized, the one of well-rounded grains, the other of grains showing more or less idiomorphic form. The two generations of rutile differed in that the rounded grains were larger and a deep red-brown color, while the prismatic grains were the more usual foxy-red. The iron ores, ilmenite and leucoxene, accounted for over half the heavy mineral suite with the varieties of zircon, colorless, brown and purple, the next most common. Tourmaline (0.I .650, E. I. .627) in a form pleochroic from black to pale brown was much less common. Green mica-like flakes of tourmaline occurred occasionally.

Monazite as well-rounded lemon yellow grains was rare, and garnets occurred in only one separation. Small, almost colorless idiomorphic crystals of anatase were found.

Size Analysis

The variety of disaggregation methods (Taylor and Georgeson, 1933, Krumbein and Pettijohn, 1938) is sufficient comment on the difficulty of obtaining an entirely disaggregated sample when even a small amount of secondary silica is present. Even with the friable Whita Sandstone, which was largely crushed between the fingers, there remained a number of aggregated grains after treating the few obdurate granules in a mortar and pestle. To avoid grain fracture, a consequence of prolonged crushing, a correction for aggregated grains was employed. Sieving was done on a Rotap allowing 20 minutes per 100 gram sample, and B.S. seives were employed.

The correction was based on the assumption that the aggregated grains in any one grade were composed of grains from all the finer grades in the same proportion as their respective grade weight. The proportion of aggregated to non-aggregated grains was obtained by grain counts of two to three hundred grains from which the propor-

TABLE 2.—*Whita Sandstone from the Tarras Valley.*

	Column 1.			Column 2.	Column 3.				Column 4.				Column 5.
RT 1.	Mic > Pg	Qm > Flsp	Qmf > Qmc		·305	·980	·302	1·23	·410	·423	·717	·668	NE.
RT 2.	Pg > Mic	Qm > Flsp	Qmf > Qmc	all	·318	1·09	·371	1·26	·391	·421	·718	·685	N.
RT 3.	Mic > Pg	Qm > Flsp	Qmf > Qmc	non-calcareous	·355	·940	·264	1·35	·418	·422	·724	·703	
RT 4.	Mic > Pg	Qm > Flsp	Qmf > Qmc		·395	1·03	·280	1·25	·380	·419	·706	·674	NNW.
RT 5.	Pg > Mic	Qm > Flsp	Qmf > Qmc		·330	·945	·268	1·26	·371	·424	·698	·658	NNE.

tionate weight was calculated. This weight was divided amongst the finer grades, correcting for aggregate grains in the coarsest grade to progressively finer grades. Normally the 44 grade (grains of diameter greater than .353 mm) was the finest affected size. No significant difference between the original and corrected size distributions was detected when the χ^2 test was applied at the 5 percent level of significance, the level adopted in all applications of the test.

One sample was prepared by crushing and also by the method using the force of crystallization of sodium sulphate. No significant difference in the size distribution was detected between the two preparations when the χ^2 test was applied. This suggests that the crushing technique and the subsequent correction is comparable with the slower, more refined technique.

The corrected size analyses were plotted as cumulative curves and histograms (figs. 2a, 2b, 3a, 3b) and the common statistics,

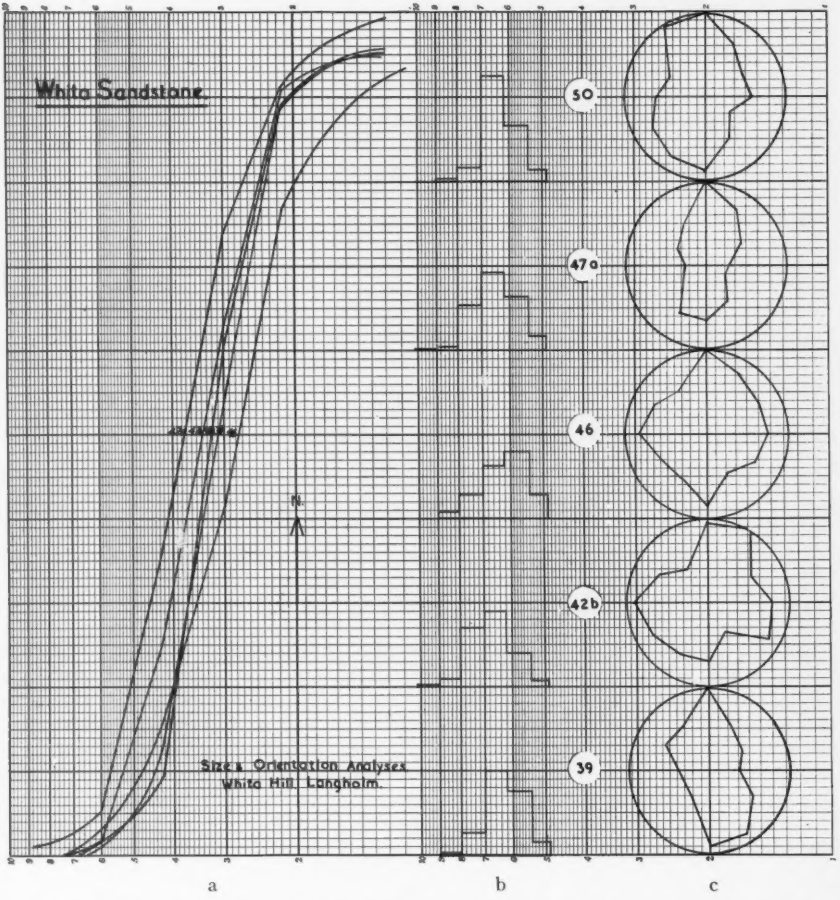


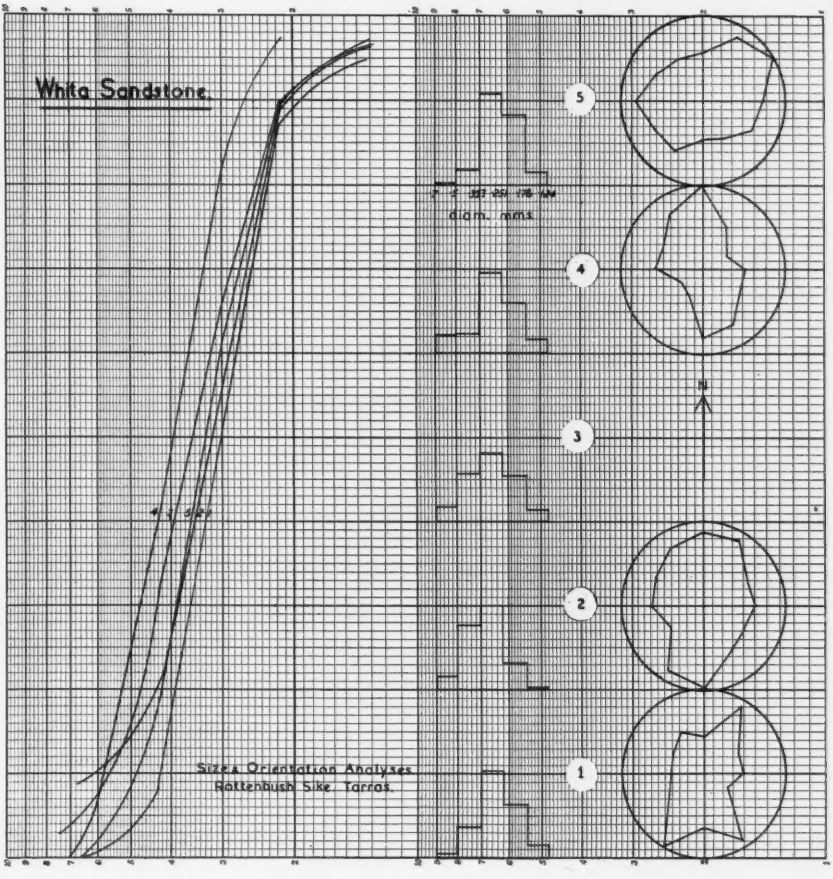
FIG. 2 a and b.—Size analyses of Whita Sandstone samples 1–5, from the Tarras water plotted as cumulative curves and histograms. c.—Orientation rosettes of samples 1–5 showing the alignment of the long axes of quartz grains in the bedding plane section.

skewness, kurtosis and Trask's sorting coefficient (Krumbein and Pettijohn, 1938, pp. 228–267) were calculated (see table 3, col. 3). It is suggestive of the homogeneity of the Whita Sandstone that even at the 10 percent level no significant difference could be detected when the χ^2 test was applied to the extreme size analyses.

Shape Analysis

Wadell's methods (1932, 1933, 1935) were followed with the exception that grain projection was avoided by use of an ocular scale and mechanical stage. Grains were magnified to approximately the same size so that the results were comparable. The mean roundness and sphericity values shown in tables 1 and 2 were derived from 50 randomly selected grains per grade sample which preliminary tests had shown to give consistent results.

Since three-quarters of any given sample by weight is contained in the 44, 60, and 85 grades, a study of shape of the 44 and 85



a b c

FIG. 3 a and b.—Size analyses of Whita Sandstone samples 39, 42b, 46, 47a and 50, plotted as cumulative curves and histograms. c.—Orientation rosettes of samples 39, 42b, 46, 47a, 50, showing the alignment of the long axes of quartz grains in the bedding plane section.

TABLE 3.—*Mean sphericity and roundness values and standard deviations of quartz grains from 44 and 85 grades of Whita Hill and Tarras Water samples*

	Whita Hill	Tarras Water
Sphericity 85 grade	.655 ± .015	.678 ± .009
44 grade	.691 ± .015	.713 ± .010
Roundness 85 grade	.415 ± .021	.422 ± .002
44 grade	.392 ± .024	.394 ± .056

grades gives a measure of shape on each side of the mean (50 percentile). Two trends were detected, an increase in roundness and a decrease in sphericity towards the finer grades. Additional samples from the 30 and 60 grades were consistent with this result which differs from that found by Russell and Taylor (1937), who found a decrease in both roundness and sphericity with decreasing grain size, but agrees with MacCarthy's (1933) findings of a progressive rounding up to the 80 mesh sieve.

A statistical comparison of the mean roundness and sphericity values from Whita Hill and the Tarras Water was carried out using Student's "t" distribution. A significant difference at the 5 percent level was found for sphericity with the higher sphericities in the Tarras Water. The higher roundness values were from the Tarras Water but the difference was not significant. The mean values are summarized in table 3.

Bokman (1952) used the length: breadth to distinguish between quartz derived from granite and schist (fig. 4a, 4c); in his diagrams 50 percent of the ratios fell in the defining class for granite, ratios of 1.0 to 1.4, while 67 percent of the ratios lay in the 1.0 to 1.6 classes. The corresponding figures for the Whita Sandstones (fig. 4b) were 32 percent and 70 percent respectively. In this context it is worth noting that no length: breadth ratios from the Whita Sandstone whether for pebbles or grains, irrespective of size, exceeded the 2.2–2.4 class.

Orientation

Preferred orientation was studied in thin sections. When sections cut parallel to the bedding plane and two cut vertically at right angles were examined each was found to possess a characteristic pattern (fig. 5). Grain orientation was defined by "least projection elongation" and "end position" of Dapples and Rominger (1945) and the method of measuring consisted of measuring the azimuth of the grain long axis with a protractor on enlarged photographs of the sections.

A study of the three resultant patterns showed that the long and intermediate axes of the grain lay parallel to the bedding plane and consequently a study of the bedding plane section showed the preferred grain orientation. This orientation was considered to be an indication of an original current direction.

The results given in tables 1 and 2, and shown as orientation rosettes in figs. 2c and 3c, indicate a general northerly current direction. This direction is in agreement with the few available current bedding measurements and also the orientation of pebbles at the single available exposure in the River Esk. The orientation is considered original

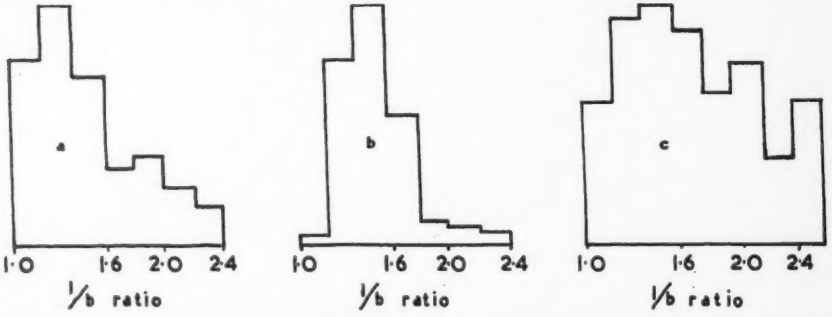


FIG. 4.—Histograms of the length:breadth ratios of quartz. a.—Quartz derived from granite, defining class 1.0–1.4 (Bokman, 1952). b.—Quartz from the Whita Sandstone. c.—Quartz derived from schist defining class 1.8–2.4 (Bokman, 1952).

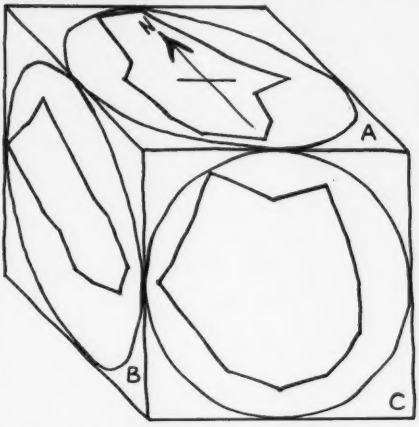


FIG. 5.—Orientation rosettes of three sections at right angles where A is parallel to the bedding, B and C are aligned N-S, and E-W, and both are normal to the bedding plane (orthographic projection).

partly because of the agreement in direction with the current bedding readings, and from the absence of any major tectonic effect to cause a re-orientation. Furthermore, the calcareous banding is undisturbed in samples with the same orientation as in non-calcareous material.

Porosity

An indication of the "effective porosity" (Krumbein and Pettijohn, 1938, p. 504) of a number of specimens was estimated from the increase in weight after immersion in water under reduced pressure, the volume of the specimen being measured directly by displacement. A check on shape effects was carried out by use of specimens of different volume and shape. The results were comparable. The average value for the porosity of six samples gave a void ratio of about 20 percent while for five calcareous samples the value was about one quarter that amount.

Summary of Petrology

The petrology can be summarized very briefly by stating that the Whita Sandstone is homogeneous with respect to size, shape, orientation and composition, both vertically and laterally. The only trends detected were an upward increase in the abundance of chert and a lateral change in sphericity.

PROVENANCE

The most likely and obvious source of sediment is the Lower Palaeozoic Southern Upland massif, which in lower Carboniferous times must have formed an upstanding peninsula or series of islands. A derivation of sediment from the Highland source which supplied material forming many Scottish Carboniferous sandstones (Bosworth, 1912) seems improbable, implying transport across the Midland Valley and through gaps in the Southern Uplands. In addition, the quartz length:breadth ratios (Bokman, 1952) are not characteristic of a metamorphic source.

The sediment was deposited by a current flowing from a general northerly direction as indicated by orientation. Consistent with this view, higher sphericities are found in the Tarras Valley than in Eskdale (see also Russell and Taylor, 1937 and MacCarthy 1933).

Firm conclusions cannot be drawn from an impoverished heavy mineral suite in which only the most stable forms are preserved because of the ambiguity introduced by possible post-depositional loss. However, well-rounded forms suggest second cycle deposits consistent with a Southern Upland source, and Mackie's (1928) list of the heavy minerals of the Silurian of the Peebles area contains all the Whita Sandstone forms except monazite as well as many unstable varieties. The rocks of the Southern Uplands also contain abundant quartz mosaics (Eckford and MacGregor, 1948) from which those of the Whita Sandstone could be secondarily derived. Chert, one primary source of mosaics, also occurs.

However to account for the monazite and the idiomorphic heavy minerals the erosion of an acid igneous mass, a further possible source of mosaics, is also suggested.

ACKNOWLEDGEMENTS

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REFERENCES

ALLEN, P., 1948, Wealden petrology: the top Ashdown Pebble Bed and the top Ashdown Sandstone: Geol. Soc. London Quart. Jour., v. 103, p. 257–320.

BOKMAN, J., 1952, Clastic quartz particles as indices of provenance: Jour. Sedimentary Petrology, v. 22, p. 17–24.

BOSWORTH, T. O., 1912, The heavy mineral grains of the Scottish Carboniferous: Geol. Mag., v. 8, p. 515–516.

DAPPLES, E. C., AND ROMINGER, J. F., 1945, Orientation analysis of fine-grained clastic sediments: a report of progress: Jour. Geology, v. 53, p. 246–261.

ECKFORD, R. J. A., AND MACGREGOR, A. G., 1948, The Upper Old Red Sandstone and the Lower Carboniferous sediments of Teviotdale and Tweedside and the stones of the Abbeys of the Scottish Borderlands: Edinburgh Geol. Soc. Trans., v. 14, p. 230–250.

FOLK, R. L., 1951, Stages of textural maturity in sedimentary rocks: Jour. Sedimentary Petrology, v. 21, p. 127–130.

FOLK, R. L. AND WEAVER, C. E., 1952, A study of texture and composition of chert: Am. Jour. Sci., v. 250, p. 498–510.

GARWOOD, E. J., 1931, The Tuedian of North Cumberland and Roxburghshire east of the Liddel Water: Geol. Soc. London Quart. Jour., v. 87, p. 97–159.

KRUMBEIN, N. C., AND PETTIJOHN, F. J., 1938, Manual of sedimentary petrology. Appleton Century Crofts Inc., New York, 549 p.

MACCARTHY, G. R., 1933, The roundness of beach sands: Am. Jour. Sci., v. 25, p. 205–224.

MACKIE, N., 1896, The sands and sandstones of eastern Moray: Edinburgh Geol. Soc. Trans., v. 7, p. 147–172.

MACKIE, W., 1928, Preliminary report on the heavy minerals of the Silurian rocks of southern Scotland: Report of the British Association for the Advancement of Science, p. 556.

NAIRN, A. E. M., 1956, The Lower Carboniferous rocks between the Rivers Esk and Annan, Dumfriesshire: Geol. Soc. Glasgow Trans., v. 22, p. 80–93.

PETTIJOHN, F. J., 1949, Sedimentary rocks. Harper and Bros., New York. 526 p.

RUBEY, W. W., 1933a, Settling velocities of gravel, sand, and silt particles: Am. Jour. Sci., v. 25, p. 325–338.

RUBEY, W. W., 1933b, The size distribution of heavy minerals within a water-laid sandstone: Jour. Sedimentary Petrology, v. 3, p. 3–29.

RUSSELL, R. D., AND TAYLOR, R. E., 1937, Roundness and shape of Mississippi River sands: Jour. Geology, v. 45, p. 225–267.

TALLMAN, S. L., 1949, Sandstone types: their abundance and cementing agents: Jour. Geology, v. 57, p. 582–591.

TAYLOR, G. L., AND GEORGESON, N. C., 1933, Disaggregation of clastic rocks in a pressure chamber: Jour. Sedimentary Petrology, v. 3, p. 40–43.

WADELL, H., 1932, Volume, shape and roundness in rock particles: Jour. Geology, v. 40, p. 443–451.

WADELL, H., 1933, Sphericity and roundness in rock particles: Jour. Geology, v. 41, p. 310–331.

WADELL, H., 1935, Volume, shape and roundness of quartz particles: Jour. Geology, v. 43, p. 250–280.

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FIGS. 1–3, MARCH, 1958

HEAVY MINERAL VARIATION IN SAN ANTONIO AND MESQUITE BAYS OF THE CENTRAL TEXAS COAST[1]

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ABSTRACT

As a further investigation of the sediments of the central Texas coast bays, heavy minerals in the sand-size fraction of the sediment samples were studied. The application of statistical analysis to heavy mineral studies by using chi-square to test for homogeneity of samples is shown. It was possible to divide the bays into areas where the relative amounts of heavy minerals were statistically homogeneous, and in the case of a bay with simple bottom configuration and sediment type it was possible to correlate the grain size distribution of the sediments with relative amounts of heavy minerals. This relationship, however, did not hold for a more complex bay. The accuracy of the laboratory procedures was investigated. The mineralogical differences between the various areas are probably real and not due to errors in laboratory methods. The heavy mineral distribution also showed that much of the sand-size sediment was carried into the bays from the barrier islands.

INTRODUCTION

The purpose of this paper is to show the application of statistical methods to heavy mineral studies by the use of chi-square to test for homogeneity of samples. By dividing the bays into areas where the relative amounts of heavy minerals were statistically homogeneous, significant variations of the heavy minerals could be shown. The geologic implications of these variations are not discussed in detail.

Comparisons of heavy mineral suites by statistical analysis have seldom been attempted. During the early years of sedimentary petrology the presentation of heavy mineral data was confined to estimated values of their abundance, but later the minerals were actually counted and percentage values of their abundance determined. These results were usually presented in tabular or graphic form, and each investigator would then use his personal judgment to draw conclusions as to the similarity of the samples. The first attempt to apply a statistical approach to this problem was that by Dryden (1935) who used the coefficient of correlation to compare heavy mineral suites. This idea was criticized by Eisenhart (1935a), who proposed the chi-square test in its place. It is the opinion of Eisenhart, Krumbein and Pettijohn (1938), and Robert L. Miller of the University of Chicago (personal communication) that there is no statistical theory developed for Dryden's use of the coefficient of correlation.

LOCATION AND DESCRIPTION OF THE AREA

This study was confined to San Antonio and Mesquite Bays which are located on the northwest coast of the Gulf of Mexico about 30 miles north of Corpus Christi, Texas (fig. 1). A complete description of these bays, their sediment types, and sedimentary environments can be found in Shepard and Moore (1955). These two bays were the only ones sampled in enough detail to allow a fair trial for the chi-square test. The only previous mineralogic investigation of the area was that by Bullard (1942) on the beach sands of the Texas coast.

METHOD OF STUDY

Grain size analyses were made of samples from the upper 5 ± cm of cores taken in the bays. The samples were dried, soaked in 0.025N sodium hexametaphosphate, $Na_6(PO_3)_6(?)$, stirred in a malt-mixer, and then wet-sieved through a 0.061 mm sieve. The sand-size material was analyzed by the Emery settling tube and the fine material was analyzed by a hydrometer size analysis (Shepard and Moore, 1955, p. 1479). After the size analyses were completed, the sand fractions were prepared for heavy mineral separations by eliminating the coarser shelly material by sieving through a 0.210 mm

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sieve (only 1 to 2 percent mineral grains and no heavies except mica were removed by this sieving), and then treating the material that passed through the sieve with hot 3 N HCl. The sand, freed of carbonates, was washed clear of acid, dried, and weighed.

The heavy mineral separations were made by using commercial acetylene tetrabromide (tetrabrom-ethane), sp. gr. 2.89, as the heavy liquid. Steep-walled funnels were used as the separation apparatus. The weighed sand fraction was placed in the acetylene

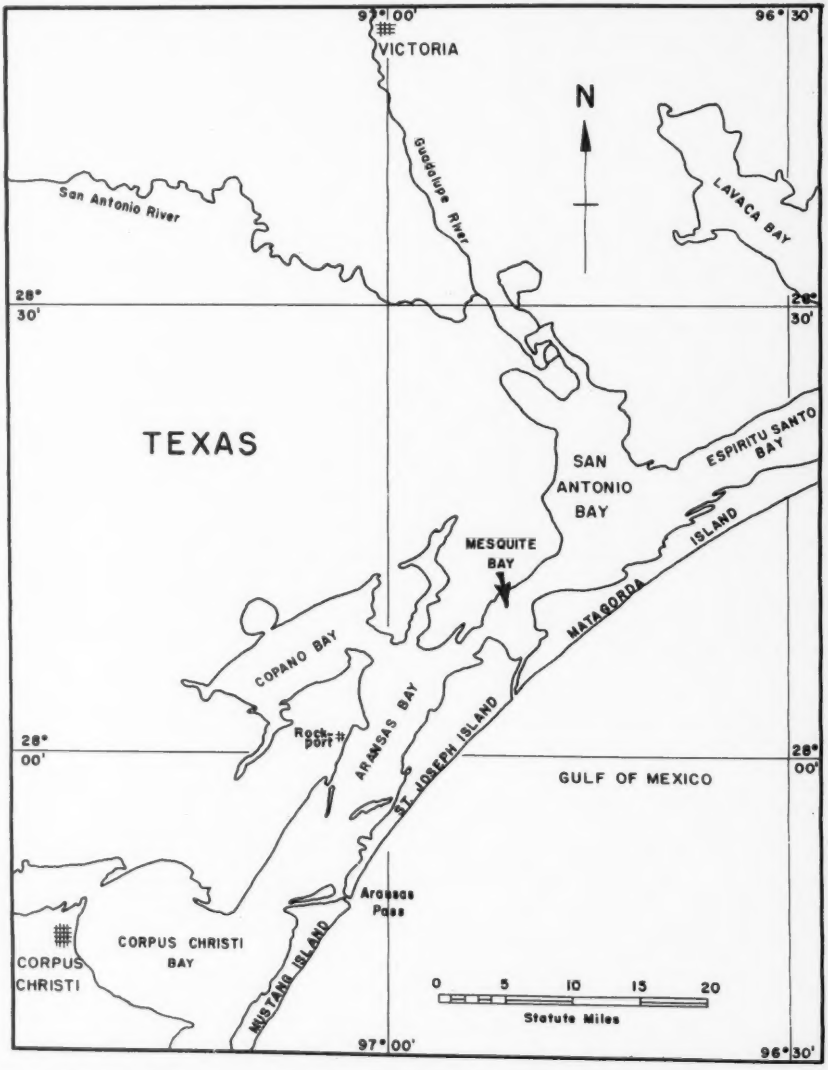

FIG. 1.—Outline map of part of Texas showing the location of the areas investigated.

TABLE 1.—*Showing loss of zircon due to sieving through 0.061 mm sieve*

Sample	Common Minerals	% Minerals in split coarser than 0.061 mm sieve	% Minerals in unsieved split	% >0.210 mm % <0.061 mm
Dune Sand (Rockport)	Black opaques	63	58	
	Tourmaline	26	8	3.5% >0.210
	Zircon	Trace	20	0.9% <0.061
	Others	11	11	
XS 387 (San Antonio Bay)	Black opaques	59	52	
	Hornblende	13	7	0.6% >0.210
	Tourmaline	15	4	
	Zircon	2	26	5.8% <0.061
	Others	11	11	

tetrabromide in the funnel, stirred thoroughly, and allowed to settle; if the sample consisted principally of very fine sand it was stirred several times during a settling period of a few hours. Acetylene tetrabromide does not completely separate the micas (specific gravities range from 2.8 to 3.1) from the light fraction so that they were not included in the heavy mineral counts. After the separation the heavy fraction was weighed and then split by means of a microsplit to a sample of about 400 grains which were mounted in Aroclor 4465. The heavy minerals from each sample were identified by traversing the slide along parallel lines and counting each grain that touched the center of the microscope cross hairs.

There are some inaccuracies in determining the heavy mineral content of the samples that are inherent in the above method of preparation because of the concentration of zircon in the finer fraction of the samples. This has been shown by Hawkes and Smythe (1931, p. 352), van Andel (1950, p. 39; 1955, p. 534), and others. The coarser silt-size material passing through the 0.061 mm sieve contains various amounts of heavy minerals that are missed in the analysis. As examples, two samples were analyzed where the separation between very fine sand and coarse silt was made by decantation using Stokes' settling velocity for quartz spheres of 0.0625 mm diameter. After being passed through a 0.210 mm sieve and treated with acid, the sand from each sample was split into two fractions. One fraction was sieved through a 0.061 mm sieve and the heavy minerals determined for the material retained on the sieve. In addition the heavy minerals were counted in the unsieved fraction. The results are shown in table 1 where it can be seen that much of the zircon is lost because of the method of size analysis. However, all the samples in this study were treated in the same manner so they are comparable one to another.

The heavy minerals in the sizes between 0.210 mm and 0.061 mm were studied, rather than a single limited size fraction or the average of two size fractions as has been advocated by some investigators. Van Andel (1950) in his study of the Rhine sediments examined the heavy minerals between 0.5 and 0.04 mm, and concluded that only in special cases was it necessary to study the various size fractions separately.

ACCURACY

The accuracy of heavy mineral studies depends on both the field sampling errors and laboratory errors. Krumbein and Rasmussen (1941) attempted to evaluate sampling and laboratory errors and concluded that they were of approximately the same order of magnitude—about 10 percent. They divided the laboratory errors into three parts: error of splitting and sieving ($1.0 \pm 0.5\%$); error of bromoform separation ($3.5 \pm 1.0\%$); and error of microsplitting, mounting, and counting ($10.0 \pm 2.0\%$), with the counting error probably being of greatest significance.

The accuracy of mineral counts can be ascertained in several ways. Dryden (1931) prepared a chart showing the probable error for several different frequencies in samples ranging from 25 to 750 grains, and pointed out that the "law of diminishing returns" would limit to a few hundred the number of grains counted. Dryden also showed that not more than two significant figures are

TABLE 2.—*Confidence intervals (95% level) showing the precision of estimates of epidote present when a large or small number of grains are counted*

Total number of grains counted	Amount epidote present by counting		Epidote will lie between these limits 95% of time	
	No. grains epidote	% epidote	No. grains epidote	% epidote
164	3	2	1 to 7	0.5 to 4
418	8	2	3 to 14	1 to 3.5

justified even if as many as 4000 grains were counted. Manning (1953) pointed out the usefulness of confidence intervals for showing the precision of mineral frequencies determined by grain counts. Table 2 shows the variation in epidote that could be expected in an area in San Antonio Bay using the smallest and largest samples counted for that area. By using table $VIII_1$ of Fisher and Yates (1949) the confidence intervals can be read off with sufficient accuracy without the somewhat laborious computations used in obtaining the intervals in table 2. Since the variation between the diagnostic minerals, hornblende and black opaques (and tourmaline), which were used to delineate the mineralogical areas, was of the order of five percent or greater, the differences between these areas are probably real.

CHI-SQUARE TEST

Many texts on statistical analysis discuss chi-square and give samples of its use. These include Dixon and Massey (1951), Fisher (1950), Snedecor (1946), and others. However, Eisenhart (1935b) works out examples using chi-square to test for homogeneity with geologic data, and his examples were used as models for this study. Mineral frequencies, not percentages, were used to calculate chi-square, and following general procedure, the five percent level of significance (or probability of a larger value of chi-square, $P=0.05$) was used to determine whether the hypothesis of homogeneity was to be rejected or not. In actual practice, the values determined in this paper gave a higher P value (0.10 to 0.85). The high values of P are probably due to the fact that the data have been made more homogeneous by grouping the minerals that occurred in small quantities (Eisenhart, 1935b, p. 143). Only five mineral categories were used: black opaques (including leucoxene), hornblende (including all the amphiboles except basaltic hornblende), tourmaline (all varieties), epidote (including the colorless varieties), and "others" (a combination of all the rest of the mineral species present). This combining is recommended because the chi-square tables have been calculated on the assumption of large samples, and therefor the smallest expected frequency should be greater than five (Fisher, 1950, p. 84). It is also necessary to count approximately the same number of grains for each sample, and if exactly the same number are counted per sample the computations are greatly simplified. Snedecor (1946, p. 24) shows the effects on chi-square of varying sample sizes.

RESULTS

Heavy minerals were counted in 165 samples, of which 44 were from Mesquite Bay and 121 from San Antonio Bay (which includes Hynes and Guadalupe bays and Mission Lake). By means of testing groups of samples for homogeneity using chi-square, various areas of the bays were found to have the same relative amounts of the various heavy mineral categories, or close enough to the same amounts to be considered statistically homogeneous.

Of the 44 samples from Mesquite Bay that were analyzed for heavy minerals, only four from the main bay are not part of a statistically homogeneous group (four samples from adjoining San Carlos Bay and Cedar Bayou would not fit either). Mesquite Bay has been divided into four areas (see fig. 2): (1) an outer zone, nearest the barrier islands, high in hornblende (42%) and opaques (32%); (2) an intermediate zone somewhat lower in hornblende (35%) and higher in opaques (37%); (3) a long narrow zone that runs NW-SE down the center of the bay that is higher in opaques (46%) than the intermediate zone and somewhat lower in hornblende (32%); and (4) a zone located in the northwest corner of the bay which is

very different from the other areas in that it is low in hornblende (11%) and high in tourmaline (23%) and opaques (56%). The mineralogical information is summarized in table 3, which includes average values for the five mineral categories, the range of these values, chi-square, and P values for each area. Also included are average values of median diameter, sorting (see Inman, 1952), and sand, silt, and clay. Table 3 shows a relationship between the heavy minerals and grain size distribution. The sediments with a high tourmaline content are sandier and better sorted than the hornblende-rich sediments of Mesquite Bay.

San Antonio Bay is far more complex than Mesquite Bay both in bottom configuration and sediment type (see Shepard

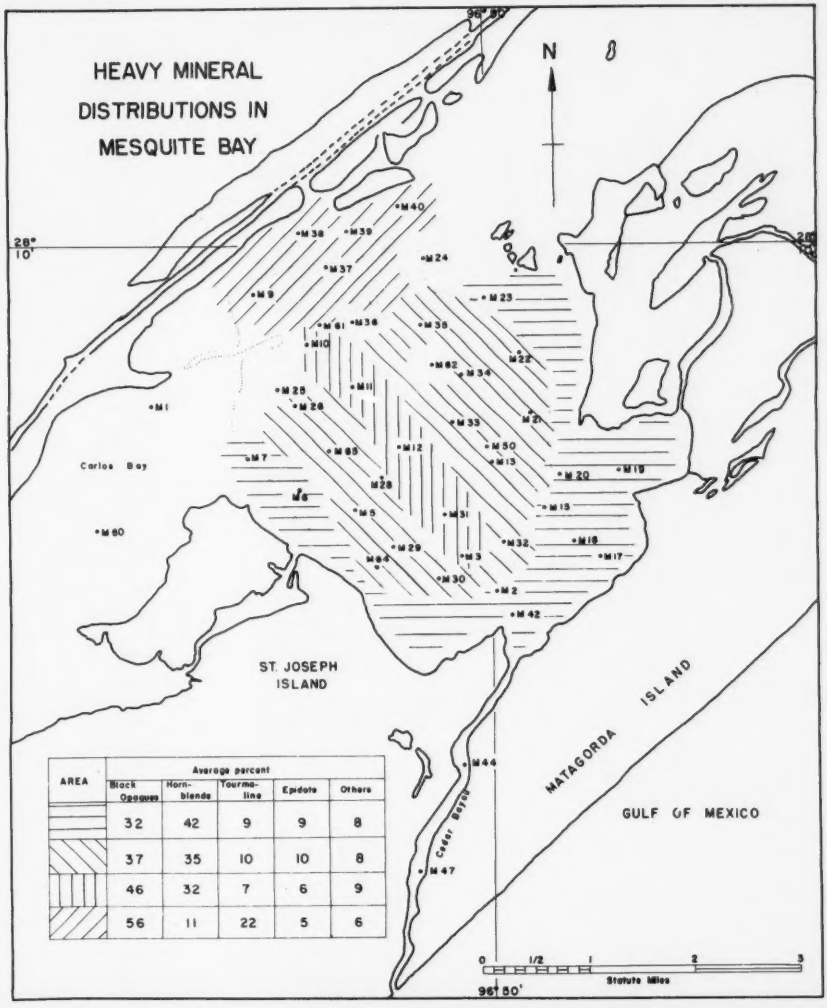

FIG. 2.—Map of Mesquite Bay showing sample locations and areas where the relative amounts of heavy minerals are statistically homogeneous.

TABLE 3.—*Summary of mineralogical data from Mesquite Bay including some size distribution measurements*

Samples in each area	Average % of Common Heavy Minerals					χ^2 P	Av. No. Grains Counted per Slide	Average Value		Average %		
	Range of Value							Range of Values		Range of Values		
Total No.	Black opaques	Horn-blende	Tour-maline	Epidote	Others		Range	Mdϕ	$\sigma\phi$	Sand	Silt	Clay
M2A, 6A, 7A, 15, 16A, 17A, 19A, 20A, 23A, 42A	32	42	9	9	8	$\chi^2=31.64$	320	3.65	3.57	51	14	25
10	29–35	38–45	8–10	6–12	6–10	$P\neq0.80$	214–377	3.23–4.08	2.93–4.10	50–74	6–21	18–40
M5, 13, 21, 22, 26A, 28A, 29A, 30A, 32A, 33A, 34A, 35A, 50A, 64A, 65A	37	35	10	10	8	$\chi^2=45.41$	310	3.62	3.47	63	14	23
15	34–41	30–39	8–13	9–12	5–10	$P\neq0.85$	250–354	3.34–3.83	1.96–4.55	54–72	6–21	10–31
M3A, 10A, 11A, 12A, 31A	46	32	7	6	9	$\chi^2=18.52$	381	3.65	3.45	62	13	25
5	42–50	29–36	5–9	5–7	8–10	$P\neq0.30$	318–465	3.32–4.06	2.40–4.35	49–68	9–19	15–33
M9A, 37A, 38A, 39A, 40A, 61A	56	11	22	5	6	$\chi^2=22.24$	353	3.40	1.84	74	12	14
6	52–62	9–12	20–25	4–7	4–7	$P\neq0.30$	295–457	3.22–3.55	0.45–3.96	60–88	9–18	3–22

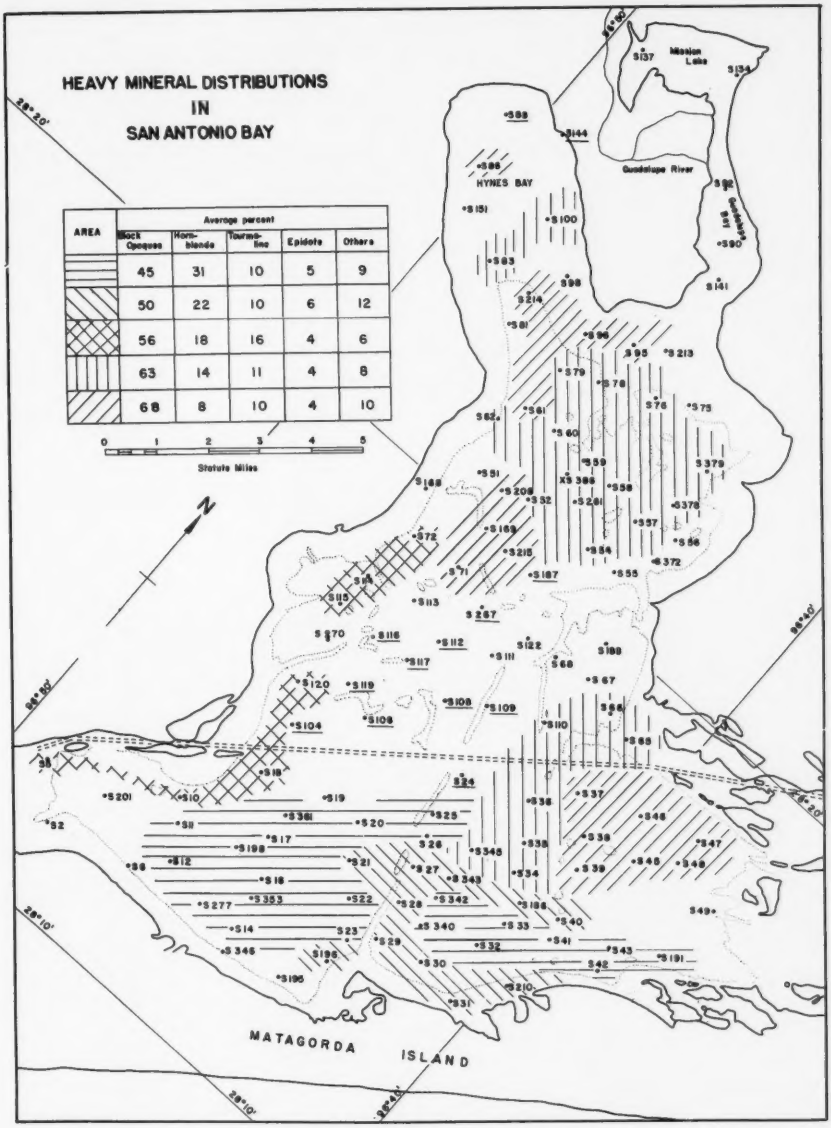

FIG. 3.—Map of San Antonio Bay showing sample locations and areas where the relative amounts of heavy minerals are statistically homogeneous. Sample locations are underlined where the samples contain less than 150 heavy mineral grains and therefore were not used in this study.

TABLE 4.—*Summary of mineralogical data from San Antonio Bay including some size distribution measurements*

Samples in each area	Average % of Common Heavy Minerals					χ^2	Av. No. Grains Counted per Slide	Average Value[1]		Average %[1]		
	Range of Value							Range of Values		Range of Values		
	Total No.	Black opaques	Hornblende	Tourmaline	Epidote	Others	P	Range	Mdϕ	$\sigma\phi$	Sand	Silt	Clay
S11A, 12A, 14A, 16A, 17A, 20A, 22A, 23A, 25A, 26A, 32A, 33A, 41A, 42A, 43A, 191A, 198A, 277B, 340D, 342D, 353D, 361D	45	31	10	5	9	$\chi^2=81.83$	332	4.98	4.00?	36	31	33
	22	40–50	27–38	7–12	4–8	6–12	$P\neq0.55$	274–418	3.45– 8.30	2.03–5.84?	12–68	10–53	16–52
S21A, 27A, 28A, 29A, 30A, 31A, 40A, 186A, 196A, 210B, 343D	50	22	10	6	12	$\chi^2=27.95$	345	4.05?	3.78?	56?	20?	24?
	11	47–54	18–26	9–13	4–8	10–13	$P\neq0.90$	265–483	3.15– 5.55	0.27–7.89?	32–91	4–27	0–41
S5A, 10A, 18A, 72A, 114A, 115A, 120A	56	18	16	4	6	$\chi^2=34.28$	374	5.44	3.45?	36	29	35
	7	51–61	15–21	13–21	2–5	5–8	$P\neq0.10$	297–443	3.18– 9.75	0.72–5.40?	6–82	5–55	12–60
S34A, 35A, 36A, 52A, 54A, 57A, 58A, 59A, 60A, 62A, 65A, 66A, 76A, 78A, 79A, 83A, 100A, 110A, 261B, 345D, 378D, 379D, XS386	63	14	11	4	8	$\chi^2=80.30$	319	6.76?	4.06?	27	32	41
	23	57–68	11–19	8–13	2–6	5–10	$P\neq0.70$	164–418	3.13–10.53?	1.02–6.47?	3–70	18–47	11–74
S37A, 38A, 39A, 45A, 46A, 47A, 48A, 61A, 71A, 86A, 95A, 96A, 169A, 208B, 214B, 215B	68	8	10	4	10	$\chi^2=60.49$	367	6.83?	4.48?	26	33	41
	16	63–72	6–10	8–13	2–5	8–13	$P\neq0.45$	265–528	356–10.92?	0.96–5.53?	7–71	16–51	13–65

[1] Averages follows by ? include some values determined by extrapolation of the cumulative curves.

and Moore, 1955, p. 1469 and 1484). Nevertheless, San Antonio Bay can be divided mineralogically into five main areas (fig. 3). Although there were 121 samples analyzed from San Antonio Bay only 84 could be fitted into homogeneous groups, and two of these groups consisted of small areas of homogeneous mineralogy containing two (S90 and S141 in Guadalupe Bay) and three (S55, S56, and S372) samples respectively which were not delineated in figure 3 because of their small extent. These two areas have an extremely low hornblende content, two to four percent. The region in the center of the bay consists principally of very clayey sediments which contain few heavy minerals. There were 13 samples whose total heavy mineral content was 150 grains or less. These samples were not used in this study. Twenty-four samples remained that could not be fitted into homogeneous groups. Determining the causes of this is beyond the scope of this paper.

Since the Guadalupe River carries no hornblende (Bullard, 1942, table 1, p. 1026; also checked by the writer), the source of this mineral is from the barrier islands (av. 35% hornblende) and the Pleistocene (?) cliffs (av. 20% hornblende) fringing the bay. Therefore, the areas of highest hornblende are located in the lower part of San Antonio Bay near the barrier islands. There are two areas of high hornblende (31%) located at the southern end of the bay (fig. 3), separated by a region with a slightly lower hornblende content (22%). Along the western side of the bay is a long narrow zone containing 18% hornblende, and having a higher tourmaline content (16%) than any other area of San Antonio Bay. Northward in the bay are areas containing much smaller amounts of hornblende, 8 and 14%. The regions with the lowest hornblende (8%) consist of an area in the lower bay and two small areas in the upper part of the bay, north of the clay and oyster reef region. The areas with a slightly higher hornblende content (14%) are located in the upper bay north of the clayey sediments, and also in the lower bay. The mineralogical information is summarized in table 4, including the average median diameter, sorting, and percentages of sand, silt, and clay. In San Antonio Bay there was no simple relationship between the heavy minerals and grain size distribution as was found in Mesquite Bay.

SUMMARY

A statistical method, the chi-square test, was used to compare heavy mineral samples. By means of this test it was possible to delineate statistically homogeneous heavy mineral areas in Mesquite and San Antonio bays. In Mesquite Bay, which has simple bottom topography and sediment types, the grain size distribution of the sediments could be correlated with their (relative) heavy mineral content; i. e., the sediments that were high in tourmaline and low in hornblende were coarser and better sorted than the high hornblende sediments of the bay. There was no such simple relationship in San Antonio Bay which has more complex sediment types and bottom topography. The hornblende distribution showed that some of the sand-size material of both Mesquite and San Antonio bays was derived from the barrier islands and carried into the bays by wind and overwash.

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REFERENCES

ANDEL, TJ. H. VAN, 1950, Provenance, transport and deposition of Rhine sediments: H. Veenman and Zonen, Wageningen, 129 p.

———, 1955, The sediments of the Rhone delta. II Sources and deposition of heavy minerals: Verh. Kon. Nederl. Geol. Mijnbouwk Gen., v. 15, p. 515–543.

BULLARD, F. M., 1942, Source of beach and river sands on the Gulf Coast of Texas: Geol. Soc. America Bull., v. 53, p. 1021–1044.

DIXON, W. J., AND MASSEY, F. J., JR., 1951, Introduction to statistical analysis. McGraw-Hill Book Co., Inc., New York, 370 p.

DRYDEN, A. L., JR., 1931, Accuracy in percentage representation of heavy mineral frequencies: Nat. Acad. Sci. Proc., v. 17, p. 233–238.

———, 1935, A statistical method for the comparison of heavy mineral suites: Am. Jour. Sci., 5th ser., v. 29, p. 393–408.

[1] Averages follows by ? include some values determined by extrapolation

EISENHART, C., 1935a, A note on "A statistical method for the comparison of heavy mineral suites": Am. Jour. Sci. 5th ser., v. 30, p. 549–553.

———, 1935b, A test for the significance of lithological variations: Jour. Sedimentary Petrology, v. 5, p. 137–145.

FISHER, R. A., 1950, Statistical methods for research workers. 11th rev. ed., Oliver and Boyd, Ltd., Edinburgh, 354 p.

FISHER, R. A., AND YATES, F., 1949, Statistical tables. Hafner Publishing Co., Inc., New York, 112 p.

HAWKES, L., AND SMYTHE, J. A., 1931, Garnet-bearing sands of the Northumberland coast: Geol. Mag., v. 68, p. 345–361.

INMAN, D. L., 1952, Measures for describing the size distribution of sediments: Jour. Sedimentary Petrology, v. 22, p. 125–145.

KRUMBEIN, W. C., AND PETTIJOHN, F. J., 1938, Manual of sedimentary petrology. D. Appleton-Century Co., Inc., New York, 549 p.

KRUMBEIN, W. C., AND RASMUSSEN, W. C., 1941, The probable error of sampling beach sand for heavy mineral analysis: Jour. Sedimentary Petrology, v. 11, p. 10–20.

MANNING, J. C., 1953, Application of statistical estimation and hypothesis testing to geologic data: Jour. Geology, v. 61, p. 544–556.

SHEPARD, F. P., AND MOORE, D. G., 1955, Central Texas coast sedimentation: characteristics of sedimentary environments, recent history and diagenesis: Am. Assoc. Petroleum Geologists Bull., v. 39, p. 1463–1593.

SNEDECOR, G. W., 1946, Statistical methods. 4th Edition, Iowa State College Press, Ames, Iowa, 485 p.

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FIGS. 1–9, MARCH, 1958

SEDIMENTARY ANALYSIS OF TERRACE DEPOSITS IN PANHANDLE FLORIDA[1]

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ABSTRACT

Sedimentary analysis of 40 samples from four previously recognized terrace surfaces in a portion of the panhandle of Florida indicates that sedimentary parameters are useful in distinguishing individual terraces. Comparison of size distribution data and heavy mineral analyses suggests that only three rather than four terraces are distinguishable in the area under study. A composite profile across the area offers supporting evidence for the presence of three rather than four terrace surfaces.

INTRODUCTION

Since Matson and Sanford (1913) first recognized three marine terraces in Florida, various authors have contributed to the literature of terraces in this region (Cooke, 1931, 1945; Vernon, 1942, 1951; Carlston, 1950; MacNeil, 1950). A recent study of the various surfaces by Trowbridge (1954) includes a tentative correlation of terraces by various authors (fig. 1).

AREA OF STUDY

The area of study lies within the Terraced Coastal Lowlands Province of Florida (*Vernon, 1951*). It is confined to the area included in the Tallahassee and Lake Talquin Quadrangle topographic maps and extends generally west from Tallahassee 26 miles and south 13 miles.

The region consists of a series of low, flat to gently rolling plains that tend to parallel the present coast. The plains are separated in places by the remnants of erosional escarpments.

Lake Talquin borders the study area to the north and the Ochlockonee River borders the area to the west. Numerous minor streams and interconnected swamps are found throughout the western portion of the area. In the eastern portion subsurface drainage and karst topography are well de-

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CLASSIFICATION	TERRACES				
	COOKE	FLINT	MacNEIL	VERNON	CARLSTON
POST WISCONSIN	SUBMERGENCE		SILVER BLUFF (5–10)	COASTAL AND SUBMARINE PLAIN	PAMLICO (20–30)
LATE WISCONSIN	EROSION			VALLEY EROSION AND LAKE FLINT MARL	PENHALOWAY (60–70)
MID– WISCONSIN	SILVER BLUFF (5) PAMLICO (25)		PAMLICO (25–30) = SUFFOLK	PAMLICO TERRACE (25) AND FORMATION	
EARLY WISCONSIN	EROSION			VALLEY EROSION	WICOMICO (90–110)
SANGAMON	TALBOT (42) PENHALOWAY (70) WICOMICO (100)	SUFFOLK (20–30) = PAMLICO	WICOMICO (100) = SURRY	WICOMICO TERRACE (100) AND FORMATION	
ILLINOIAN	EROSION			VALLEY EROSION	SUNDERLAND (150–160)
YARMOUTH	SUNDERLAND (170) COHARIE (215)	SURRY (100) = WICOMICO	OKEFENOKEE (150) = SUNDERLAND	OKEFENJKEE DEPOSITS (150)	
KANSAN	EROSION			VALLEY EROSION	
AFTONIAN	BRANDYWINE (270) (CITRONELLE)	TRAIL RIDGE (180–240) (?)	(?)	COHARIE DEPOSITS (220)	COHARIE (190–210)
NEBRASKAN	EROSION			VALLEY EROSION	

MODIFIED FROM TROWBRIDGE

FIG. 1.—Marine terraces of different writers on Atlantic and East Gulf Coastal Plains.

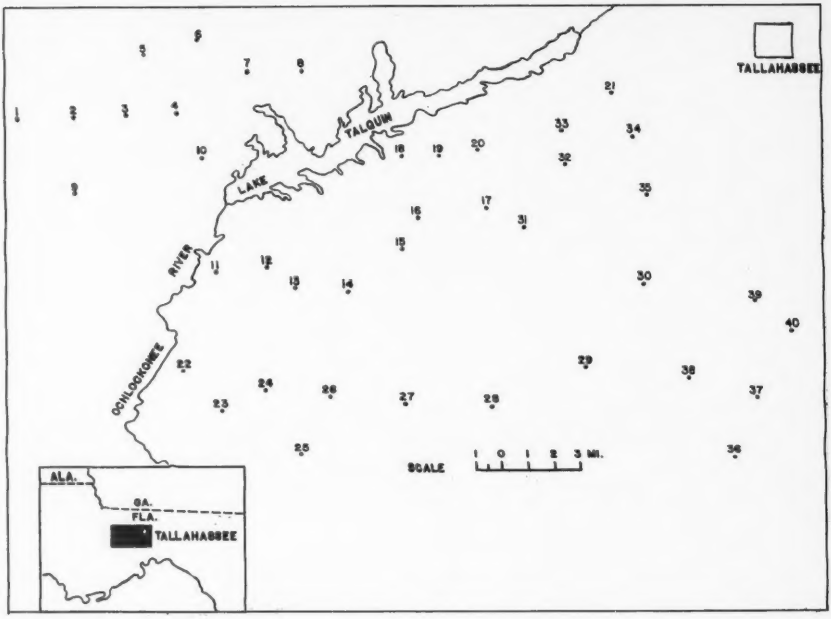

FIG. 2.—Index map of Tallahassee and Lake Talquin Quadrangles and sample localities.

TABLE 1.—*Heavy mineral percentages*

30′			60′–105′			115′–150′			170′–220′		
Sample No.	A	B	Sample No.	A	B	Sample No.	A	B	Sample No.	A	B
36	0.08	0.02	22	0.61	0.10	11	0.14	0.18	1	0.18	0.33
37	0.04	0.02	23	0.13	0.07	12	0.29	0.35	2	0.22	0.23
38	0.01	0.01	24	0.09	0.10	13	0.20	0.07	3	0.50	0.37
39	0.10	0.01	25	0.26	0.06	14	0.24	0.09	4	0.13	0.26
40	0.07	0.09	26	0.16	0.03	15	0.14	0.28	5	0.06	1.07
			27	0.16	0.04	16	0.15	0.13	6	0.23	1.36
			28	0.17	0.07	17	0.14	0.47	7	0.18	1.18
			29	0.17	0.03	18	0.34	0.15	8	0.22	0.65
			30	0.12	0.01	19	0.39	0.06	9	0.24	0.13
			31	0.21	0.33	20	0.35	1.00	10	0.47	0.40
			32	0.17	0.22	21	0.15	0.10			
			33	0.15	0.07						
			34	0.12	0.31						
			35	0.44	0.21						

A = From whole sample.
B = From $\frac{1}{4}$–$\frac{1}{8}$ mm fraction.

TABLE 2.—*Comparison of sedimentary parameters of four terraces*

Terrace Levels	Average Mean Size	Sorting Coef.	Roundness	Average Percent Heavy Minerals	
				Total	$\frac{1}{4}$–$\frac{1}{8}$ mm
170′–220′	.357	1.64	Subangular few grains subrounded	.215	.681
115′–150′	.298	1.75	same	.222	.252
60′–105′	.286	1.77	same	.228	.118
5′–30′	.257	1.41	same	.094	.032

veloped where the Tertiary limestones lie at or near the surface.

FIELD STUDY

Samples were collected from four terrace surfaces previously recognized by Vernon (1942), Carlston (1950) and MacNeil (1950). Elevations of sample stations were taken from nearby bench marks, road intersections and elevations at section corners. The four surfaces sampled are the area above the 170 foot contour line (Vernon's 170–220 foot terrace); the area between 115 and 150 feet (upper limit approximates MacNeil's Okefenokee shoreline); the area between 60 and 105 feet (Wicomico terrace limits by Vernon); and the area below the 30 foot contour line (upper limit of Pamlico of several authors). Sample localities were chosen so that the stations would form traverses closely parallel to the apparent trends of the terraces (fig. 2).

At each station, four grab samples were collected from the corners of a square ten feet on edge and from a depth in excess of six inches. These were mixed, coned, and quartered. A composite sample of about 250 grams was bagged for each station.

Ten U. S. Standard sieves and the pan were used to sieve the material. The mesh diameters of the screens ranged from .833 mm to .088 mm. Fifteen minute periods of shaking in the Ro-tap were used to separate 200 gm of material from each sample.

Heavy mineral separations were conducted on the total samples and on the $\frac{1}{4}$ mm to $\frac{1}{8}$ mm size fraction. In both cases, 20 gm samples were used. Iron oxide coatings on individual sand grains of several samples were removed by treatment with stannous chloride prior to the heavy mineral separation in bromoform.

The percentages by weight of the heavy minerals are listed in table 1. The heavy mineral average percentages for the total samples of the three upper terraces are very similar (0.215, 0.228, 0.222, from high to low) while the lowest surface has a much lower average concentration (0.081). However, the average percentages for heavy minerals in the $\frac{1}{4}$–$\frac{1}{8}$ mm fraction are fairly distinctive for each surface sampled (table 2; fig. 3). The highest terrace has the highest concentration of heavy minerals in this fraction (.681) and the concentration, on the average, decreases with a decrease in elevation. In no sample was the heavy mineral concentration as great as 1.5 percent.

Ten samples of the heavy mineral concentrate in the $\frac{1}{4}$ to $\frac{1}{8}$ mm size fraction were

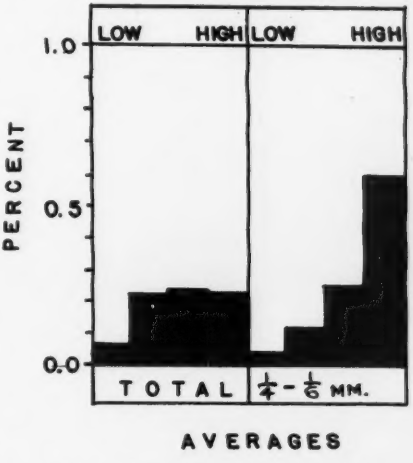

FIG. 3.—Comparison of heavy mineral percentages by terrace surfaces.

TABLE 3.—*Distribution and abundance of heavy minerals by terraces*

Terrace Elevations	Sample No.	Abundance of heavy minerals in $\frac{1}{4}$–$\frac{1}{8}$ mm grade									
		Ilmenite-magnetite	Rutile	Kyanite	Tourmaline	Zircon	Staurolite	Monazite	Garnet	Sillimanite	Leucoxene
170–220	5	C	VA	VA	C	C	VR	VR	VR	VR	VR
	7	C	A	VA	A	C	VR	VR	VR	VR	VR
115–150	12	A	C	A	C	VR	VR	VR	VR	VR	R
	17	VA	A	A	R	R	VR	VR	VR	VR	VR
	20	VA	C	C	R	C	VR	VR	VR	VR	VR
60–105	24	VA	A	VR	VR	VR	C	VR	VR	VR	VR
	31	C	A	C	R	A	VR	VR	VR	VR	VR
	34	A	VA	C	A	VR	VR	VR	VR	R	VR
5– 30	37	A	VA	C	VR	C	VR	VR	VR	VR	VR
	40	A	A	A	C	C	R	VR	VR	VR	VR

VA Very Abundant (30%)
A Abundant (21–30%)
C Common (11–20%)
R Rare (5–10%)
VR Very Rare (5%)

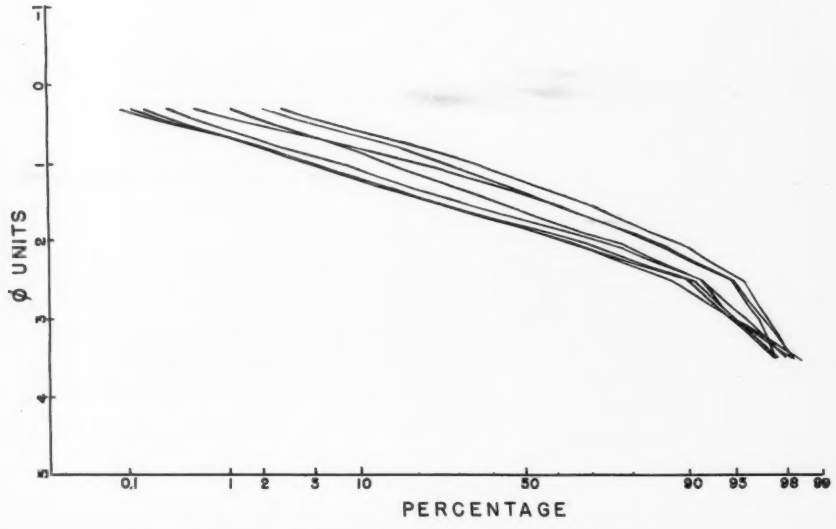

FIG. 4.—Size distribution curves for samples between 170′–220′.

examined for mineral identification and relative abundance. Two samples each were taken from the high and low terraces and three each from the two intermediate levels. The 10 minerals identified are present in all samples examined (table 3).

Ilmenite-magnetite, rutile, and kyanite are the most common minerals. Zircon is common in the high and low terrace material while tourmaline varies from abundant to rare in all four terraces. All other minerals are for the most part very rare.

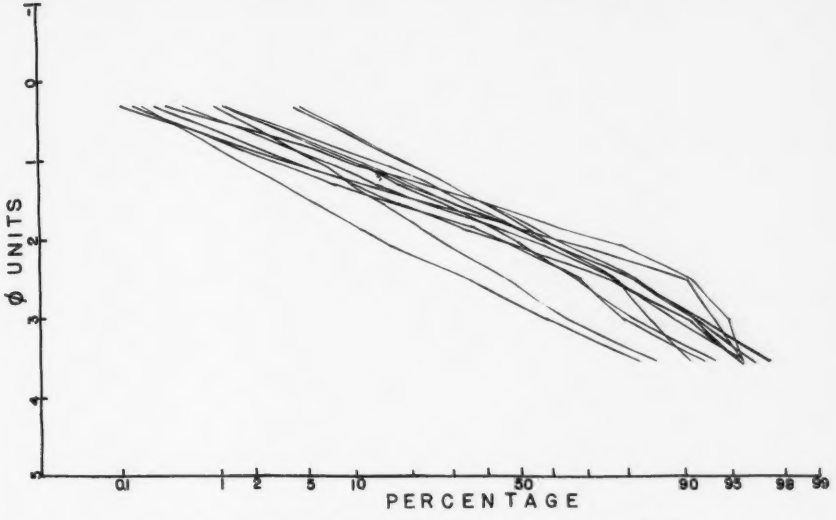

FIG. 5.—Size distribution curves for samples between 115′–150′.

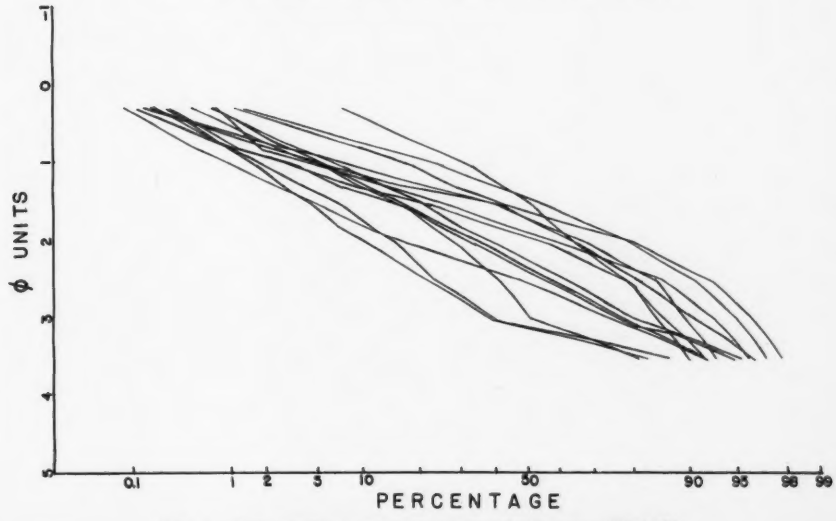

FIG. 6.—Size distribution curves for samples between 60′–105′.

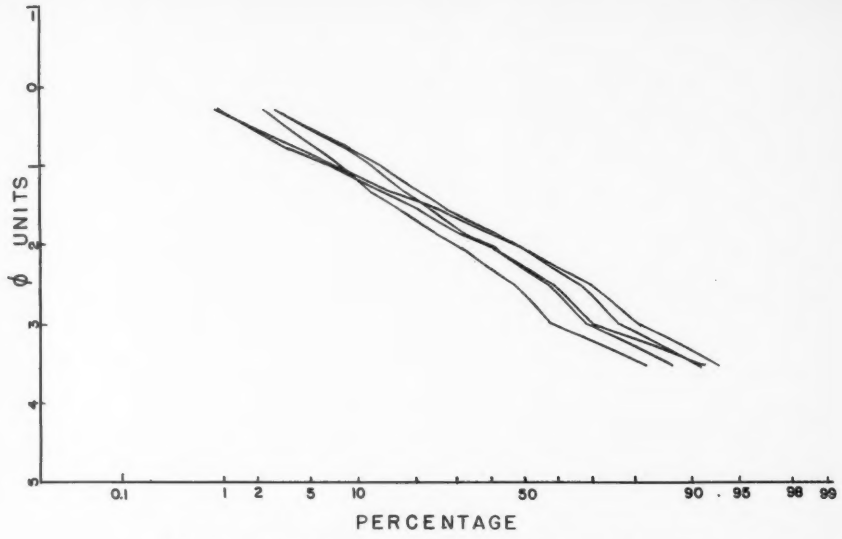

FIG. 7.—Size distribution curves for samples between 5′–30′.

STATISTICAL PROCEDURE

Cumulative frequency curves for each of the samples separated in the Ro-tap are presented on probability paper. The screen diameters are plotted in terms of phi-scale units. A sample with normal distribution would plot on probability paper as a straight line diagonal. Deviations from a normal distribution are indicated by deflections from the straight line. Steepening of the curve

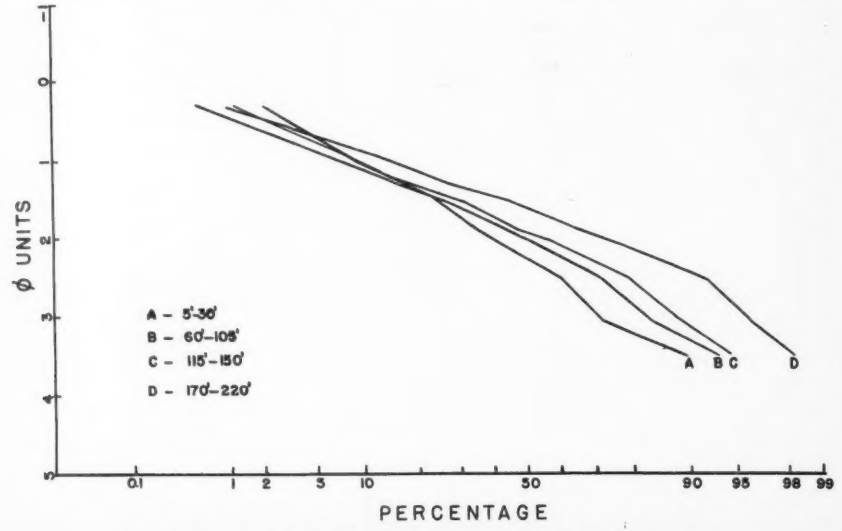

FIG. 8.—Average size distribution curves of samples from four terraces.

FIG. 9.—Composite topographic profile across Lake Talquin and Tallahassee Quadrangles, Florida.

towards the fine sizes suggest increased current activity and removal of the fines. Flattening of the curve towards the fine sizes suggests a decrease in current action and subsequent increase of fine size percentages in the deposit. All the curves for the high (170–220 foot) terrace are very similar and show normal distribution down to the 2.5 phi size where the curves indicate a sharp reduction in fine material (fig. 4).

The curves for the two intermediate (115–150 foot and 60–105 foot) terraces are very much alike (figs. 5 and 6) but differ from the high terrace material in being finer grained.

The five curves for samples from the 5–30 foot terrace are markedly similar (fig. 7). The curves indicate that these sands are the finest of the four groups examined.

A comparison of the average mean size for the samples of each terrace indicates a positive correlation with elevation (table 2).

Composite cumulative frequency curves representing the average grain size distribution for each terrace have been plotted (fig. 8). The curves indicate nearly normal distribution and similarity of size for the samples from the two intermediate surfaces. The high surface material indicates a coarser nature by the steepening of the curve at the 2.5 phi line while the low terrace shows a finer size by the flattening of its curve at the 3.0 line.

The average coefficient of sorting for each terrace deposit indicates that all sands are very well sorted (table 2).

TOPOGRAPHIC PROFILE

As a check against the data obtained by sedimentary analyses a composite topographic profile was drawn across the study area. This profile is based on five parallel profiles drawn at 1.25 mile intervals diagonally across the Lake Talquin and Tallahassee quadrangle region (fig. 9). Three moderately dissected surfaces separated by two fairly distinct scarp zones are readily distinguished in the composite profile. The high terrace varies from 186 feet to 242 feet above sea level with an average elevation of 213 feet (based on 52 readings). The middle terrace ranges in elevation from 95 feet to 154 feet with an average elevation of 119 feet (based on 133 readings). The low surface has an average elevation of 38 feet

(based on 57 readings) with a range from 25 feet to 59 feet above sea level.

SUMMARY AND CONCLUSIONS

It is apparent that sedimentary parameters are useful in distinguishing the high and the low terraces, but are less so for the intermediate terraces. It may well be that in this region only three distinct terrace surfaces exist.

The average mean grain size decreases from the high to the low terrace. Although the average mean sizes for each terrace differ, the difference between the two intermediate surfaces is much smaller than those between these surfaces and the high and low terraces. The same relationships apply to the average coefficients of sorting. The degree of roundness does not distinguish between the sediments of each terrace.

Heavy mineral concentrations based on total samples do not readily distinguish different terrace levels. Only the lowest terrace surface consistently shows a distinctive heavy mineral concentration whether in the total sample or $\frac{1}{4}$–$\frac{1}{8}$ mm size fraction. However, average percentages of heavy minerals present in the $\frac{1}{4}$–$\frac{1}{8}$ mm size fraction clearly distinguish the high and low terraces from each other and from the two intermediate surfaces. The intermediate surfaces are less readily distinguished from each other on this basis. The total percentages of heavy minerals in the fraction show a net increase from low to high elevations.

In the area of Lake Talquin and Tallahassee quadrangles the evidence from sedimentary studies as well as topographic profiles strongly suggests the preservation of only three terraces. The composite profile lends supporting evidence to conclusions based on sedimentary data above.

An extension of this type of investigation into other areas should clarify whether or not the differences in the sedimentary parameters of the region studies are applicable on a broader basis. The characteristic curves on probability paper, the variations in average mean size diameters and heavy mineral concentrations in specific size fractions appear to offer evidence for a positive correlation between specific terraces and their sedimentary parameters.

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Dr. E. H. Lund and Mr. F. L. Haley of Florida State University assisted in the heavy mineral studies. The U. S. Forest Service generously donated maps.

REFERENCES

CARLSTON, C. W., 1950, Pleistocene history of coastal Alabama: Geol. Soc. America Bull. v. 61, 1119–1130 p.

COOKE, C. W., 1931, Seven coastal terraces in the southeastern states: Washington Acad. Sci. Jour., v. 21, p. 503–513.

———, 1945, Geology of Florida: Florida Geol. Survey Bull. 29, p. 12–13.

MATSON, G. C., AND SANFORD, S., 1913, Geology and ground waters of Florida: U. S. Geol. Survey Water Supply Paper 319, p. 31–35.

MACNEIL, F. S., 1950, Pleistocene shorelines in Florida and Georgia: U. S. Geol. Survey Prof. Paper 221-F, 95–107 p.

TROWBRIDGE, A. C., 1954, Mississippi and Gulf Coast terraces and sediments as related to Pleistocene history—a problem: Geol. Soc. America Bull., v. 65, p. 793–812.

VERNON, R. O., 1942, Geology of Holmes and Washington Counties, Florida: Florida Geol. Survey Bull. 21, p. 15–28.

———, 1951, Geology of Citrus and Levy Counties, Florida: Florida Geol. Survey Bull. 33, p. 17–52.

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FIG. 1, MARCH, 1958

PROPOSED CLASSIFICATION AND TERMINOLOGY OF ROCKS IN THE SERIES BAUXITE-CLAY-IRON OXIDE ORE[1]

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ABSTRACT

In only a small number of rock types is chemical composition used, up to this time, as the main criterion in their petrographic classification and terminology. A new classification and terminology of rocks in the series bauxite-clay-iron oxide ore based on their quantitative mineral composition is proposed herein. The terms laterite and bauxite are explained not only from their substantive, but also from their genetic, point of view. Laterite is a relatively untransported weathered product, containing free aluminum hydroxide, derived *in situ* from the parent rock, whereas bauxite is a transported weathered product (detrital mode of occurrence). Both of these rocks, however, have the same mineral composition.

INTRODUCTION

Bauxite rocks are characterized by containing as their essential or auxiliary constituents some of the aluminum hydroxides, i.e. gibbsite, $\gamma Al(OH)_3$, boehmite, $\gamma AlO \cdot OH$, and diaspore, $\alpha AlO \cdot OH$.[2] The minerals next in significance in bauxite rocks are clay minerals of the kaolin group (first of all, kaolinite and halloysite), and iron oxide minerals, mainly hematite, Fe_2O_3, but also goethite, $\alpha FeO \cdot OH$, lepidocrocite, $\gamma FeO \cdot OH$, and less abundantly even the amorphous hydrate, $Fe_2O_3 \cdot nH_2O$. The above-mentioned minerals can be found in bauxite rocks in many combinations, and therefore in various quantitative ratios. Thus various rocks ranging from pure bauxite up to pure kaolinite clay or, with the increase of iron oxide minerals, up to high grade iron oxide ore may be found.

No suggestion is found in scientific literature, as yet, of a classification of rocks in the series bauxite-clay-iron oxide ore. Correspondingly, there is marked nonuniformity in the terminology of these rocks. Even in basic textbooks of sedimentary petrology, as e.g. in the books by Barth, Correns, and Eskola (1939), Svecov (1948), Pettijohn (1949), or A. B. Ruchin (1953) we do not find complete, or all-embracing, information on the terminology of these rocks, although there is no doubt that the rocks of this series are especially important from the industrial point of view.

What has been, so far, the main reason for this gap in the system of organization of sedimentary rocks? It is probable that, first of all, it is the lack of reliable data upon the quantitative mineral composition of the rocks of this series. There exists, indeed, a countless number of chemical analyses of the rocks in question, but their recalculation into mineral composition has not always been realistic, and it has often led to the "ascertainment" of hypothetical minerals, which may not, or do not occur in the rock at all, or at least, only in insignificant amounts. On the contrary, the minerals which actually occur in the rock as its essential constituents often may not have been considered in the calculation. These differences between the hypothetical and actual mineral composition can be reliably ascertained only by means of a very detailed petrographic analysis, which is made possible in the case of fine-grained sedimentary rocks only by more-detailed methods developed during the last two decades. Such efficient methods of complex petrographic analysis used nowadays are X-ray analysis, differential thermal analysis, weight-thermal analysis, study in electron microscope, and removal of ferruginous pigment and semi-quantitative microscopic determination of the mixture of highly dispersed minerals by determining the average refractive index in immersion liquids, etc. Without the use of these methods, which obviously include the classical methods, among which there is always in the first place the microscopic study of thin sections of rocks, it is impossible to ascertain highly detailed petro-

[1] Manuscript received April 15, 1957.
[2] In the last year Gedeon (1956) ascertained in Hungarian bauxites also bayerite, $\alpha Al(OH)_3$.

graphic characteristics of the rocks of the above-mentioned series.

From the mere chemical data it is not possible to form a petrographic classification in this series of rocks; instead only an evaluation can be made for industrial purposes. Even modern advanced industrial technology, however, is not content with mere quantitative chemical analysis of these raw-materials, but it requires increasingly more data of their mineral composition. At the same time, however, one should not ignore chemical analysis and its definite importance in the classification of these rocks because the results of the quantitative chemical analysis remain continually a desirable and almost indispensable supplement of the general characteristics of any sedimentary rock. By means of the combination of the chemical data with the results of the modern physical and physical-chemical methods of mineral analysis it is possible to obtain at the present time a correct quantitative, or perhaps more often a semiquantitative, estimation of the mineral composition of the rock.

The writer has found the shortcomings of the classification and terminology of the rocks in the series bauxite-clay-iron oxide ore during his petrographic studies of various types of these rocks from the territory of Czechoslovakia, and during his studies of otherwise very detailed and modern literature (e. g., Problems of Clay and Laterite Genesis, 1952). The principal difficulty in their classification lies in the fact that there does not exist any uniform opinion among the authors on the basic definition of the terms of bauxite and laterite. In the writer's earlier works (Konta, 1954a, b) there has been made an attempt to clear up this problem, starting from the terminology suggested by Fox (1932). Not even the thorough work of Fox, however, has brought a satisfactory explanation of these terms which will satisfy the modern demands of petrography. There is agreement only that the weathering process of alumino-silicate rocks leading to the genesis of aluminum hydroxides and iron oxide minerals is called by most authors lateritization, and only exceptionally bauxitization.

TABLE 1.—*Main types of primary profiles of weathered rocks and their transposed derivatives*

Primary profile (superjacent derivative of a parent rock)	Detrital mode of occurrence (transposed material)
Kaolin	Kaolinite clay
Laterite	Bauxite
Primary iron oxide ore (Ferruginous gossan)	Secondary iron oxide ore

PROPOSED CLASSIFICATION

That is why it is well possible to propose the use of the name "laterite" only for a rock containing free aluminum hydroxides which is connected with its parent rock and has an evident and immediate relation to it (direct primary profile). In other words laterite is proposed to designate only a rock which is a relatively untransported, altered residuum and derivative that usually overlies the parent rock, but is in contact with the parent. On the contrary, the name "bauxite" means such a sedimentary rock with free aluminum hydroxides, that has no evident relation to its parent rock. There exists between both these names such a relationship as has been used between the names of kaolin and kaolinite clay (see table 1). This point of view is strictly petrographic, as it starts from the mineral composition and genesis of the rock.

Some authors (e.g. Rooksby, 1951, Schaufelberger, 1953) assert more the compositional point of view, and consider bauxite to be only such sedimentary rock that contains an insignificant quantity of iron but such a high content of aluminum that it is industrially important. Laterite, on the contrary, contains a considerable quantity of iron oxide minerals, and is always of a reddish brown color. According to other authors (Lacroix, 1914, Lapparent, 1930) bauxite is composed predominantly of "amorphous" aluminum monohydrate, whereas laterite contains mainly crystalline $Al(OH)_3$. Further different opinions of various authors for the use of the term laterite or bauxite are summarized in the thorough work of Vadász (1946).

Similar attempts at exclusively compositional classification have been extended by some authors to other sedimentary rocks. Thus, for example, Lapparent (1923) in the system of sedimentary rocks has placed quartzite and radiolarite in the same

group, for both these rocks are closely similar from the compositional point of view, although the former belongs to psammites and the latter to silicites. These classifications have not found, however, much support in petrology but they can have a certain importance for industry.

Further differences in the classification and terminology of the bauxite rocks arose at the time when the research workers improved and made more detailed the petrographic investigation of pelites. In this manner we find at present such terms as: high-alumina clays, high-alumina fireclays, alumina-rich laterite clays, first-grade diaspore, diasporite, argillaceous diasporite, etc. (Problems of Clay and Laterite Genesis, 1952.) These terms testify, indeed, to their authors' effort to express more closely the petrographical character of the rock; they are chosen, however, rather in an isolated way and do not respect the already existing terms in this series of rocks. The first three terms have not been formed on the basis of quantitative data and have rather the character of geologic terms, since they characterize the strata of bauxitic clays up to argillaceous bauxites with rapidly changing contents of aluminum hydroxydes in short ranges (Foose, 1944; Keller, 1952; Bolger and Weitz, 1952; Sherman, 1952). Not even further terms, e.g. diasporite or argillaceous diasporite (although the authors, Bolger and Weitz, 1952, make use of quantitative ratios of minerals) are quite acceptable, for similarly other authors could introduce further analogous terms like gibbsitite or boehmitite. In this manner, old and customary terms of bauxite and laterite would become useless. A similarly complicated situation in the terminology could arise with the rocks, in which, as an essential constituent occurs hematite, or goethite and lepidocrocite. In the above-mentioned cases the correct name should be diaspore bauxite, boehmite bauxite, gibbsite bauxite, hematite iron ore, goethite iron ore, etc., or in the case of primary profiles of weathered rocks, gibbsite laterite, gibbsite-hematite laterite, etc. These names not only stress the

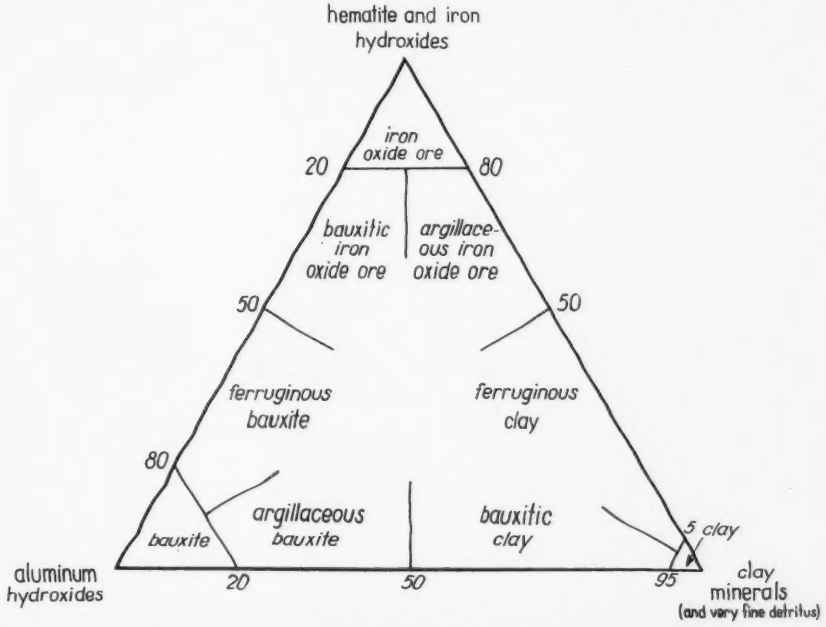

FIG. 1.—Proposed classification and terminology in the series of rocks: bauxite-clay-oxidic iron ore.

main mineral in the rock, but also show the origin of the rock at the same time.

The proposed classification and terminology in this work (fig. 1) is based on the quantitative mineral composition and has its source in the three main types of rocks: bauxite-clay-iron oxide ore. Among these three main types there exist in nature all possible gradations. Thus arise the transitional types, the names of which are formed according to the names of the main types of rocks.

In the triangular projection it is possible to see that bauxite can contain up to 20% (by weight) of other minerals than those of aluminum hydroxides. It can be expected that this limit will satisfy even the experts in industry. Similarly, iron oxide ore can contain up to 20% of minerals other than hematite or iron hydroxides. With clay, the limit for admixture of iron oxide minerals and aluminum hydroxides is essentially lowered, namely up to mere 5%. Such a decrease is necessary, for higher admixtures have a considerable influence upon technological quality of clay.

If the bauxitic iron oxide ore, or the argillaceous iron oxide ore contains only one iron oxide mineral, it is possible to name such rock in a more detailed way and shorten its name. For instance it is possible to introduce the following names: bauxitic hematite ore, bauxitic goethite ore, argillaceous hematite ore, argillaceous goethite ore, etc.

In the diagram, a sandy admixture is not considered, although in clays or some iron oxide ores it is present. For the sake of classification of rocks, in the series iron oxide ore-clay-sand it is possible to form analogically similar triangular projection and to mark in it in a similar way the transitional types of rocks.

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REFERENCES

Barth, T. F. W., Correns, C. W., and Eskola P., 1939, Die Entstehung der Gesteine: II. Teil, Berlin, Springer Verlag, 422 p.

Bolger, R. C., and Weitz, J. H., 1952, Mineralogy and origin of the Mercer fireclay of North-central Pennsylvania: Problems of clay and laterite genesis, p. 81–93.

Foose, R. M., 1944, High-alumina clays of Pennsylvania: Econ. Geology, v. 39, p. 557–577.

Fox, C. S., 1932, Bauxite and aluminous laterite: Techn. Press Ltd., 2. ed., London, 312 p.

Gedeon, T. G., 1956, Bayerite in Hungarian bauxite: Acta Geol. Acad. Sci. Hungary, v. 4, p. 95–106.

Keller, W. D., 1952, Observations on the origin of Missouri high-alumina clays: Symposium "Problems of clay and laterite genesis," p. 115–134.

Konta, J., 1954a, Lithological and chemical investigation of the bauxites of Markušovce (Eastern Slovakia): Rozpravy Čsl. akademie věd, v. 64, sešit 4, p. 11–64.

———, 1954b, Contribution to the petrography and genesis of the bauxite of Rychnov: Acta Univ. Carolinae, 1, No. 9, p. 37–63.

Lacroix, A., 1914, Les latérites de la Guinée: Extrait de Nouvelles arch. du Muséum. 5. série, tome 5, p. 255–356.

Lapparent, J. De, 1923, Lecons de pétrographie. Paris, 501 p.

———, 1930, Les bauxites de la France méridionale: Mém. du service de la carte géol., Paris, p. 1–146.

Pettijohn, F. J., 1949, Sedimentary rocks. Harper and Brothers, New York, 526 p.

Problems of clay and laterite genesis, 1952, Am. Inst. Min. Met. Eng., New York, 24[illegible] p.

Rooksby, H. P., 1951, Oxides and hydroxides of aluminium and iron: X-ray identification and crystal structures of clay minerals. Monography edit. by G. W. Brindley, London, p. 261.

Ruchin, A. B., 1953, Osnovy litologii: Gostoptechizdat, Leningrad, 671 p.

Schaufelberger, P., 1953, Was ist Laterit? Geochim. et cosm. Acta, v. 3, p. 47–52.

Sherman, G. D., 1952, The genesis and morphology of the alumina-rich laterite clays: Problems of clay and laterite genesis, p. 154–161.

Svecov, M. S., 1948, Petrography of sedimentary rocks (Petrografia osadochnych porod): Gosgeolizdat, Moskva, 387 p.

Vadász, E., 1946, A magyar bauxitelöfordulasok földtani alkata. (Die geologische Entwicklung und das Alter der ungarischen Bauxitvorkommen.) Ann. Inst. publ. Geol. Hung., v. 37, p. 173–286.

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FIGS. 1–5, MARCH, 1958

SIZE DISTRIBUTION OF ROCK TYPES IN STREAM GRAVEL AND GLACIAL TILL[1]

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ABSTRACT

Studies of alluvial gravel demonstrate that the percentage of a given rock type in the gravel varies with the size distribution of the particles in the sample. The variations are large and account for differences of 25 percent or more between lithologies of unsized samples of the same formation. Accordingly, most pebble counts of alluvial gravel should utilize restricted grade sizes determined by sieving or other methods of accurate size measurement.

Studies of the coarse fraction of Kansan till from northwestern Missouri and northeastern Kansas indicate that the lithology of till also varies with the mean diameter of the particles in the sample. The variations are, however, less than one-fifth as great as the variations found in alluvial gravel. This contrast in size-lithology variation may represent a fundamental difference between till and alluvial gravel. Some restriction of grade size is desirable for pebble counts of till. Sorting by visual estimation of size is probably accurate enough for most routine descriptions of till.

INTRODUCTION

The relation of particle size to the mineralogy of samples of sand, silt, and clay has been studied by many workers during the past 25 years (Trowbridge and Shepard, 1932; Rubey, 1933; Russell, 1936; Rittenhouse, 1942; Andel, 1950, p. 21–28; Grim, 1950, p. 13–21; Mielenz and King, 1955, p. 213–215). As a consequence, virtually all modern mineralogical studies of fine-grained sediments give careful attention to the particle size of the component minerals. In contrast, the influence of size on the petrology of pebbles, cobbles, and boulders often has been overlooked. Trowbridge and Shepard (1932) were among the first to extend grain counts that were made within restricted grade sizes into sizes larger than 2 mm. Their data clearly show the influence of size on lithology. A number of later workers have published data illustrating varying amounts of lithology-size interdependence in the larger grade sizes (U. S. Bureau of Reclamation, 1950, p. 139; Davis, 1951, p. 182–186; Lamar and Reynolds, 1951; Rubey, 1952, p. 164; Dreimanis and Reavely, 1953, p. 247–248; Horberg and Potter, 1955, p. 12–15; Potter, 1955, p. 5–7). Moreover, many studies have been made using a single grade size, or index grade size, thus inferring that particle size bears an important relation to the lithology of gravels (Thiele, 1938; Krumbein, 1942, p. 1377; Kay and Graham, 1943, p. 144; Plumley, 1948, p. 55; and Holmes, 1952, p. 1000). The purpose of this paper is to further document the extent and nature of the relation between lithology and particle size in coarse-grained sediments.

[1] Abstract published in Geol. Soc. America Bull., v. 67, p. 1764. Manuscript received October 7, 1957.

PEBBLE COUNTS

Counts were made from spot samples collected from fresh surfaces of outcrops whose locations are given in table 1. Each sample weighed between 50 and 100 pounds. Particles with diameters between 1 mm and 64 mm were divided into Udden grade sizes by sieving, and particles larger than 64 mm were divided into Udden grade sizes by direct measurement of intermediate diameters. Individual counts were made of the particles in each grade size larger than 8 mm for 39 samples of till and stream gravel. Counts were made of sizes smaller than 8 mm for 18 of the 39 samples. A total of 153 separate counts were made of the various fractions from the 39 samples; however, only counts made through a wide range of sizes are given in table 2.

Fragments larger than 2 mm were identified megascopically or with the aid of a hand lense, and those smaller were identified with the aid of a binocular microscope. Ten thin sections were made to better identify selected rock specimens. Megascopic classification was made as detailed as possible, some pebble counts having as many as 50

TABLE 1.—*Location of gravel samples*

All samples are from Missouri except Sample 15 which is from Utah

Sample Number	County	Township	Range	Section	Quarter	Geologic Classification
1	Platte	52	33	4	NE	Kansan till
2	Platte	52	33	21	NE	Kansan till
3	Platte	53	33	18	SE	Kansan till
4	Platte	54	33	16	NE	Kansan till
5	Clinton	54	33	13	NW	Kansan till (weathered)
6	Platte	54	34	21	NE	Kansan till (weathered)
7	Platte	51	34	34	NE	Kansan outwash
8	Platte	52	33	4	NE	Kansan outwash
9	Platte	53	34	23	SW	Kansan outwash (weathered)
10	Platte	53	34	8	NW	Recent gravel, Jowler Creek
11	Platte	54	37	12	NW	Recent gravel, Short Creek
12	Jackson	50	32	12	SW	Recent gravel, Missouri River
13	Lafayette	51	27	32	SE	Recent gravel, Missouri River
14	Buchanan	57	35	6	SW	Recent gravel, Missouri River
15	Uintah	4	23	33	NE	Terrace gravel, Green River

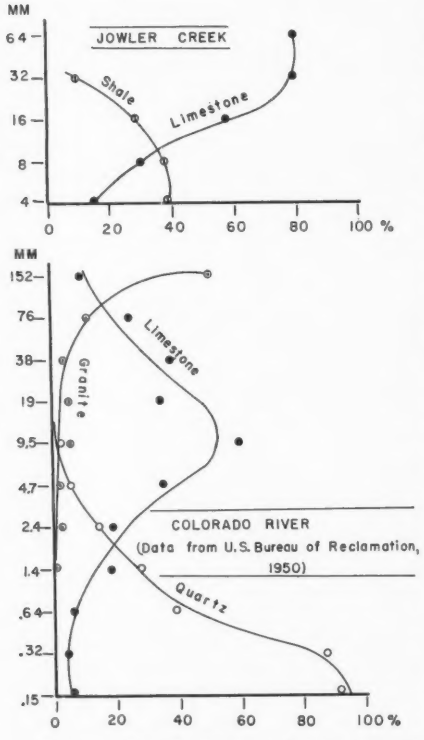

FIG. 1.—Size distribution of rock types in Jowler Creek, an ephemeral stream, and in the lower part of Colorado River.

rock types. The various rock types were later placed in the 12 lithologic groups which are given in table 2.

Samples of Kansan till presented special problems in the separation of the coarse fraction from the matrix of silt and clay. The till is too hard to be sieved when dry, and if it is sieved when wet, a large portion of the shale and sand-stone fragments will disintegrate. The best method of separation was found to be merely hand picking fragments larger than about 2 mm from moist till. This was done by breaking the till into successively smaller pieces until all the larger rock and mineral fragments were exposed. In this manner about 80 percent of the shale and sandstone could be recovered without breakage. This method had the disadvantage of being tedious inasmuch as more than 4 hours must be taken to process a single sample of till.

The scarcity of cobbles and larger pebbles in the tills studied is another difficulty encountered during the study. I was unable to obtain more than 20 pebbles and cobbles larger than 32 mm from 100 pound samples of unweathered till. Likewise, in a study of till from Ontario, Dreimanis and Reavely (1953, p. 247) collected samples weighing between 20 and 150 pounds which yielded a maximum of only 68 pebbles and cobbles larger than 13.3 mm. To overcome this difficulty, I counted some of the larger fractions from lag concentrates within gullies which cut unweathered till (see sample 1,

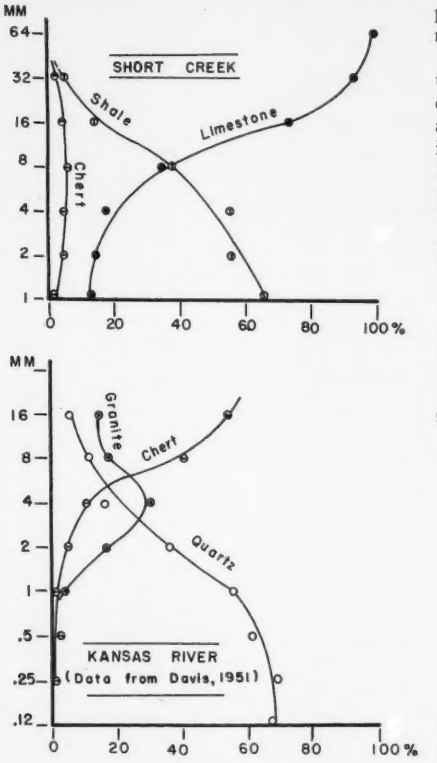

FIG. 2.—Size distribution of rock types in Short Creek, a small perennial stream, and in Kansas River, a large river draining much of northern Kansas. Note the exceptionally rapid change in limestone content between 8 and 16 mm in gravel from Short Creek.

table 2). However, counting lag concentrate is not wholly satisfactory because shale and other friable rocks originally in the till are commonly destroyed. Also, the original stratigraphic position of the rocks forming the lag concentrate is undetermined.

ALLUVIAL GRAVEL

Variations of lithology with grade size for a number of different alluvial gravels are given in figures 1, 2, 3, and 4. Numbers on the vertical scale are the sizes of the openings of the screens on which the fractions were retained. Only the most abundant constituents are plotted on the diagrams; complete counts are given in table 2 and in the references cited.

The diagrams illustrate lithologic variations between grade sizes which commonly exceed 25 percent. The diagrams indicate, also, that different rock types reach a maximum abundance in different grade sizes. For example, in Colorado River gravel (fig. 1) granite is most abundant in sizes larger than 100 mm, limestone is most abundant between 2 mm and 100 mm, and quartz is most abundant in sizes below 2 mm.

The most common method of making field counts is to outline an area on an outcrop which is judged to contain about 100 pebbles. All the pebbles are then collected from this area and used for the count. This

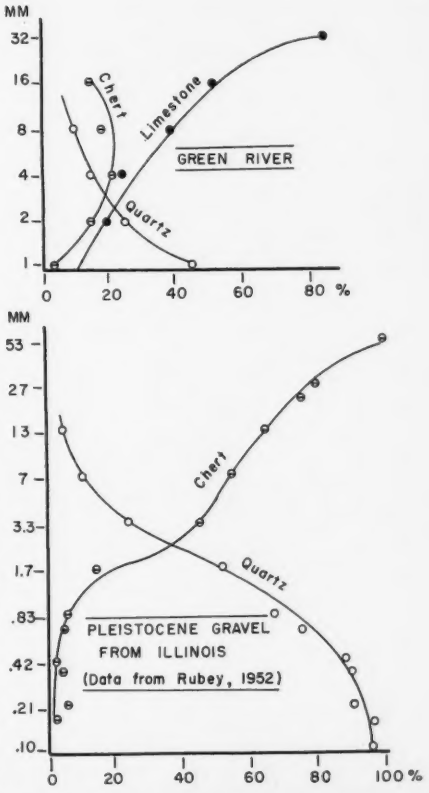

FIG. 3.—Size distribution of rock types in Pleistocene terrace gravels from Utah and Illinois.

TABLE 2.—*Pebble counts*

Sample	Size mm	Number of Pebbles	Pink Quartzite	Greenstone and Graywacke	Misc. Metamorphics	Dark Igneous	Light Igneous	Feldspar	Quartz	Chert	Limestone	Sandstone	Shale	Limonite Concentrations
			Percent by Number											
1	256–512	9	—	—	—	—	11	—	—	—	89	—	—	—
	128–256	55	—	—	—	—	4	—	—	—	96	—	—	—
	32– 64	5	—	—	—	—	20	—	—	—	80	—	—	—
	16– 32	28	—	7	—	—	—	—	4	—	75	11	—	4
	8– 16	54	—	4	—	—	2	—	—	2	67	6	18	2
	4– 8	71	—	3	1	—	6	1	—	4	68	4	7	4
2	64–128	3	—	—	—	—	33	—	—	—	66	—	—	—
	32– 64	9	—	32	11	—	—	—	—	—	56	—	—	—
	16– 32	59	3	15	12	2	—	—	—	10	41	7	10	—
	8– 16	185	1	18	7	4	8	—	5	5	44	—	5	3
	4– 8	230	1	17	4	2	13	—	4	7	43	1	7	1
3	32– 64	3	—	—	—	—	—	—	—	—	100	—	—	—
	16– 32	18	—	—	—	6	—	—	—	—	78	—	11	6
	8– 16	77	—	—	—	—	1	—	—	5	78	14	—	1
	4– 8	349	—	1	—	—	2	—	—	5	71	9	—	11
	2– 4	281	—	1	—	—	3	1	1	3	66	7	4	14
4	64–128	3	—	—	—	—	—	—	—	—	100	—	—	—
	32– 64	8	—	13	25	13	—	—	—	—	38	—	—	—
	16– 32	34	—	29	6	—	9	—	3	—	50	—	—	—
	8– 16	75	—	12	7	1	9	—	3	8	41	4	11	4
	4– 8	142	—	10	4	—	8	3	4	1	48	1	18	3
5	128–256	2	100	—	—	—	—	—	—	—	—	—	—	—
	64–128	8	50	13	13	—	—	—	—	—	—	25	—	—
	32– 64	15	13	7	7	7	13	—	7	7	—	33	—	7
	16– 32	55	27	5	18	2	7	—	7	11	—	22	—	—
	8– 16	82	10	26	12	1	6	2	7	27	—	4	2	2
6	128–256	1	100	—	—	—	—	—	—	—	—	—	—	—
	64–128	26	65	12	8	8	4	—	—	—	—	4	—	—
	32– 64	59	50	10	8	7	3	—	2	—	—	8	—	1
	16– 32	67	43	10	16	7	7	—	—	6	—	3	—	6
	8– 16	188	22	12	18	—	11	—	7	24	—	1	—	6
7	64–128	11	—	—	—	—	—	—	—	—	100	—	—	—
	32– 64	27	—	7	4	—	4	—	—	—	74	7	—	4
	16– 32	73	4	7	4	—	1	—	1	3	66	8	—	4
	8– 16	202	2	7	5	—	5	—	3	4	45	5	9	13
	4– 8	239	2	15	3	—	10	1	3	5	43	4	7	7
8	64–128	10	—	—	—	—	—	—	—	—	100	—	—	—
	32– 64	33	—	—	—	—	3	—	—	—	93	3	—	—
	16– 32	129	2	2	—	—	2	—	1	4	72	7	5	5
	8– 16	218	—	4	3	1	6	1	1	7	67	4	—	6
	4– 8	471	1	7	4	1	12	—	2	8	54	5	3	3
	2– 4	245	1	9	2	1	18	1	5	2	50	3	5	3
9	64–128	7	86	—	14	—	—	—	—	—	—	—	—	—
	32– 64	31	55	3	13	6	6	—	—	3	—	10	—	3
	16– 32	99	20	7	11	1	8	—	2	17	1	17	9	6
	8– 16	285	5	34	10	—	12	—	7	20	—	4	2	5
	4– 8	470	3	30	9	—	26	1	7	15	—	2	3	5

TABLE 2—(*continued*)

Sample	Size mm	Number of Pebbles	Pink Quartzite	Greenstone and Graywacke	Misc. Metamorphics	Dark Igneous	Light Igneous	Feldspar	Quartz	Chert	Limestone	Sandstone	Shale	Limonite Concentrations
			Percent by Number											
10	64–128	15	20	—	—	—	—	—	—	—	80	—	—	—
	32– 64	46	2	—	2	—	—	—	—	2	80	4	9	—
	16– 32	163	6	—	1	—	1	—	—	1	56	7	28	1
	8– 16	343	1	1	3	—	1	—	—	9	30	9	38	9
	4– 8	445	2	1	2	—	2	1	3	7	14	12	39	15
11	64–128	11	—	—	—	—	—	—	—	—	100	—	—	—
	32– 64	62	—	—	—	—	—	—	—	2	93	—	5	—
	16– 32	148	1	—	—	—	—	—	—	5	72	5	13	3
	8– 16	191	—	—	1	—	—	—	—	6	34	12	36	12
	4– 8	462	—	—	—	—	3	—	—	4	18	10	54	11
	2– 4	644	—	—	—	—	3	2	2	3	15	6	57	11
	1– 2	632	—	—	—	—	—	3	9	1	12	3	66	4
12	256–512	1	—	—	—	—	—	—	—	—	100	—	—	—
	128–256	4	—	—	—	—	—	—	—	—	100	—	—	—
	64–128	27	—	—	—	—	—	—	—	4	96	—	—	—
	32– 64	47	2	10	9	—	4	—	—	4	60	2	2	6
	16– 32	109	4	8	10	2	18	1	9	10	26	—	2	9
	8– 16	210	4	17	12	2	26	4	9	8	8	—	3	6
	4– 8	358	—	8	6	—	30	25	9	14	4	1	1	2
	2– 4	409	1	7	1	—	14	35	24	5	2	—	3	6
13	32– 64	1	—	—	—	—	—	—	—	—	100	—	—	—
	16– 32	85	7	5	8	4	15	—	4	25	22	2	8	—
	8– 16	339	2	4	11	2	29	3	7	21	9	2	10	1
	4– 8	375	1	5	5	—	35	23	8	13	4	1	6	—
	2– 4	1302	—	3	5	1	11	36	35	5	3	—	1	—
14	64–128	3	—	—	—	—	—	—	—	—	100	—	—	—
	32– 64	81	5	1	2	—	5	—	—	2	76	4	2	1
	16– 32	323	5	7	6	2	17	—	3	13	38	1	6	—
	8– 16	604	3	8	16	—	23	7	7	14	17	1	4	—
	4– 8	400	1	8	6	—	34	17	6	8	13	2	5	1
	2– 4	338	1	4	5	—	23	24	16	5	17	2	5	2
15	32– 64	6	17	—	—	—	—	—	—	—	83	—	—	—
	16– 32	60	—	—	15	—	3	—	—	13	60	7	—	—
	8– 16	167	—	—	18	—	—	1	10	17	44	10	—	—
	4– 8	52	—	—	15	—	—	2	15	25	27	15	—	—
	2– 4	495	—	—	15	—	2	11	24	14	20	9	—	—
	1– 2	154	—	—	10	—	1	15	44	3	—	25	—	—

method has the advantage of being simple and rapid; however, it has the disadvantage of yielding little information concerning the size-lithology characteristics of the material counted. Without this information it is commonly impossible to interpret the significance of the counts. For example, different counts of Missouri River gravel (fig. 4) could indicate various limestone percentages between 10 and 90, the actual value depending on the dominant size of the pebbles in the portion of the outcrop chosen for study. Thus, without knowledge of size-lithology variations, these large differences in limestone content could be incorrectly attributed to changes in provenance or other causes.

An accurate description of gravel lithology can only be made by first separating the sample into grade sizes and then making

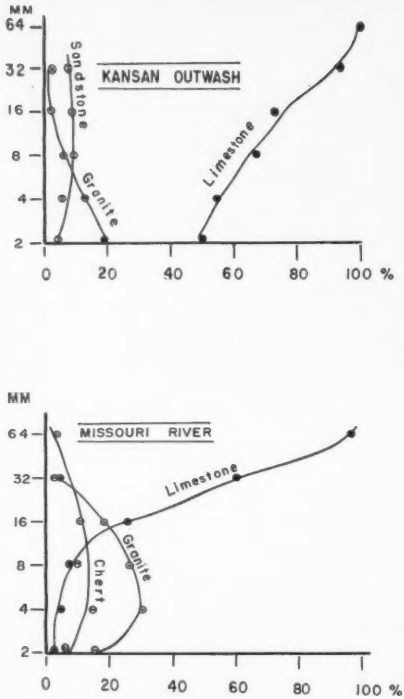

FIG. 4.—Size distribution of rock types in a modern stream gravel from the Missouri River compared with the size distribution of rock types from a nearby deposit of glacial outwash. The magnitude of the lithologic change in outwash appears to be always less than is found in normal river gravel.

counts of each grade size. However, in practice such a large amount of effort is commonly not justified. If counts are to be made for correlation purposes, the use of a single grade size, or index grade size (Holmes, 1952, p. 1000), may be satisfactory. If the primary purpose is to search for indicator stones and lithologic percentages are of minor importance, then a field count using a wide range of sizes may be superior to the use of an index grade size. Nevertheless, regardless of the primary purpose of the counts, the probability of size-lithology variations should be taken into account in the presentation and interpretation of the field and laboratory data.

A restriction of counts to within one Udden grade size has proved satisfactory for the purposes of constructing the size-lithology diagrams presented with this paper. A closer size restriction would, however, have been even better for gravels showing extreme lithologic variations between grade sizes. Inasmuch as a closer size restriction requires larger samples, a practical consideration is the maximum sample size which can be handled during the study. For the present study samples weighing between 50 and 100 pounds were necessary in order to obtain significant numbers of pebbles and cobbles in the larger fractions. A larger sample would have been difficult to transport to the laboratory, particularly where sampling sites were considerable distances from roads.

GLACIAL TILL

The lithology of the larger fragments in till varies to some degree with variations in grade size, but the variation is not as large nor as clearly defined as it is in alluvial gravel. However, the lithologic change between 1/16 mm and 2 mm is striking. Thin sections of unweathered Kansan till show a predominance of quartz in fragments smaller than $\frac{1}{4}$ mm; pebble counts indicate a predominance of limestone in fragments larger than 2 mm. A similar change in lithology between 1/16 mm and 2 mm has been noted in till from northeastern Illinois (Horberg and Potter, 1955, p. 12–15). Data from Illinois are plotted in figure 5. Note that, despite the marked lithologic change between 1/16 mm and 2 mm, the lithologic change is small in sizes larger than 4 mm.

Large changes of lithology of till shown in table 2, samples 1–6 are only present where the total number of pebbles counted is statistically insignificant. In counts of more than 50 pebbles from unweathered till the lithologic variation between grade sizes does not exceed 7 percent. The lithologic variation of weathered till is somewhat greater; however, this variation is probably affected by weathering and hence would not reflect the original nature of the till.

Other workers have also found that pebbles and cobbles from till have only small variations of lithology between grade sizes (Järnefors, 1952; Dreimanis and Reavely, 1953). Inasmuch as some variation in lithology exists, most pebble counts of till should be made of particles within re-

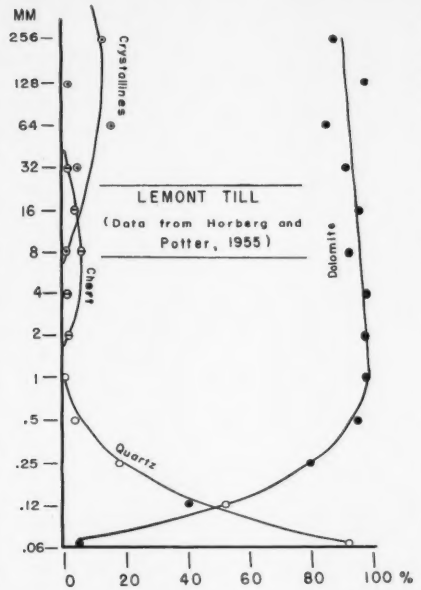

FIG. 5.—Size distribution of rock types in glacial till from Illinois. Significant lithologic changes in sizes larger than 2 mm are lacking in this sample.

stricted grade sizes. However, for many purposes a careful estimation of particle size by eye should be sufficiently accurate.

The contrast in the size distribution of rock types between alluvial gravel and glacial till probably constitutes a fundamental difference between the two types of sediments. This contrast is caused by factors such as differences in provenance, attrition and breakage during transportation, and selective transportation of particles. Selective transportation is in itself a complex problem involving size, shape, and specific gravity of the transported particle combined with the density, viscosity, and velocity of the transporting medium. Sufficient data to evaluate these variables have not been collected.

Studies of particle shape, particle markings, and sorting of particle sizes are generally more useful than pebble counting as methods of differentiating till and alluvium. However, pebble counting may be of some use in studying highly weathered alluvium, alluvium incorporated in mud flows, and similar deposits which are difficult to differentiate from till.

The size-lithology characteristics of outwash are intermediate between the alluvium and till (samples 7, 8, and 9, table 2; fig. 4; also see Davis, 1951, p. 185). As outwash gravel is transported from its glacial source, it probably approaches the sorting characteristics of normal alluvium more rapidly than it approaches the size-lithology characteristics of normal alluvium. If this is true, pebble counts may aid in differentiating normal alluvial gravel from glacial outwash.

The characteristics of alluvial and glacial deposits in mountainous regions have not been studied. Therefore, results of this study should not be applied to those deposits without further pebble counts. Differences in provenance are generally not large between alluvial and glacial deposits from a single alpine valley; consequently lithology contrasts may not be as great as in an area of continental glaciation.

CONCLUSIONS

1.—The lithology of alluvial gravel varies with the mean diameter of the sample.

2.—Most pebble counts of alluvial gravel should be made within carefully restricted grade sizes.

3.—The lithology of pebbles, cobbles, and boulders from till varies only slightly with the mean diameter of the particles.

4.—This contrast in the size distribution of rock types between alluvial gravel and glacial till probably constitutes a fundamental difference between the two types of sediments.

5.—This difference is potentially useful in determining the origin of certain gravel-bearing deposits.

ACKNOWLEDGEMENTS

This paper is adapted from a portion of a dissertation presented to the faculty of the Graduate School of Yale University in partial fulfillment of the requirements for the degree of Doctor of Philosophy. The work was under the guidance of Professor R. F. Flint of Yale University and was supported by the Missouri Geological Survey. Professor A. D. Howard of Stanford University has offered a number of helpful suggestions concerning the present paper.

REFERENCES

ANDEL, T. H. VAN, 1950, Provenance, transport and deposition of Rhine sediments; Wageningen, H. Veenman & Zonen, 129 p.

DAVIS, S. N., 1951, Studies of Pleistocene gravel lithologies in northeastern Kansas: Kansas Geol. Survey Bull. 90, p. 173–192.

DREIMANIS, A., AND REAVELY, G. H., 1953, Differentiation of the lower and the upper till along the north shore of Lake Erie: Jour. Sedimentary Petrology, v. 23, p. 238–259.

GRIM, R. E., 1950, Application of mineralogy to soil mechanics: Illinois Geol. Survey Rept. Inv. 146, 21 p.

HOLMES, C. D., 1952, Drift dispersion in west-central New York: Geol. Soc. America Bull., v. 63, p. 993–1010.

HORBERG, L., AND POTTER, P. E., 1955, Stratigraphic and sedimentologic aspects of the Lemont drift of northeastern Illinois: Illinois Geol. Survey Rept. Inv. 185, 23 p.

JÄRNEFORS, B., 1952, A sediment-petrographic study of glacial till from the Pajala District, North Sweden: Geologiska Föreningens, Band 74, p. 185–214.

KAY, G. F., AND GRAHAM, J. B., 1943, The Illinoian and post-Illinoian Pleistocene geology of Iowa: Iowa Geol. Survey, v. 38, p. 1–262.

KRUMBEIN, W. C., 1942, Flood deposits of Arroyo Seco, Los Angeles County, California: Geol. Soc. America Bull., v. 53, p. 1355–1402.

LAMAR, J. E., AND REYNOLDS, R. R., 1951, Notes on the Illinois "Lafayette" gravel: Illinois Acad. Sci. Trans., v. 44, p. 95–108.

MIELENZ, R. C., AND KING, M. E., 1955, Physical-chemical properties and engineering performance of clays, *in* Paske, J. A., *et al.*, Clays and clay technology: California Div. Mines Bull. 169, p. 196–254.

PLUMLEY, W. J., 1948, Black Hills terrace gravels: a study in sediment transport: Jour. Geology, v. 56, p. 526–577.

POTTER, P. E., 1955, The petrology and origin of the Lafayette gravel: Part 1. Mineralogy and petrology: Jour. Geology, v. 63, p. 1–38.

RITTENHOUSE, GORDON, 1942, Transportation and deposition of heavy minerals: Geol. Soc. America Bull., v. 54, p. 1725–1780.

RUBEY, W. W., 1933, The size-distribution of heavy minerals within a water-laid sandstone: Jour. Sedimentary Petrology, v. 3, p. 3–29.

———, 1952, Geology and mineral resources of the Hardin and Brussels Quadrangles (in Illinois): U. S. Geol. Survey Prof. Paper 218, 179 p.

RUSSELL, R. D., 1936, The size distribution of minerals in Mississippi River sands: Jour. Sedimentary Petrology, v. 6, p. 125–142.

THIELE, S., 1938, Diluvialstratigraphische Untersuchungen und Geschielbezahlungen in der Umgebung von Kiel: Zeitschrift fur Geschiebeforschung und Flachlandsgeologie, Band 14, p. 20–47.

TROWBRIDGE, A. C., AND SHEPARD, F. C., 1932, Sedimentation in Massachusetts Bay: Jour Sedimentary Petrology, v. 2, p. 3–37.

U. S. BUREAU OF RECLAMATION, 1950, Geological investigations: Boulder Canyon Project Final Reports, Part III—Preparatory Examinations, Bull. 1, 232 p.

JOURNAL OF SEDIMENTARY PETROLOGY, VOL. 28, NO. 1, PP. 95–96
FIGS. 1–2, MARCH, 1958

AN OCCURRENCE OF FLAT-TOPPED RIPPLE MARKS[1]

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ABSTRACT

Flat-topped ripple marks from the Pennsylvanian rocks of Oklahoma have been compared with similar ripple marks formed at low tide along the modern Florida coast. It is concluded that flat-topped ripple marks indicate bevelling, by wave-lets, in water approximately two inches, or less, deep.

Flat-topped ripple marks were observed in the field by Lawrence Miller, in the course of mapping for his master's thesis. The ripple marks which he saw may be found in sandstones of the Wewoka Formation, in section 5, township 13 north, range 12 east, Okmulgee County, Oklahoma. As a result of his discovery, the present author has sought, and found, similar ripple marks in other formations in the Carboniferous section of Oklahoma.

[1] Manuscript received October 23, 1957.

Modern flat-topped ripple marks were located, and studied, on a tidal flat, near Bald Point, about 40 miles south of Tallahassee, Florida. This study, and the photographs for the present note, were made in the winter and spring of 1957. McKee (1957) has published photographs which he had previously made of at least two kinds of flat-topped ripple marks.

The Bald Point ripple marks were developed along a more-or-less linear bar oriented at about 45 degrees to the shore line. The

FIG. 1.—Ruler, standing on edge in the sand, across flat-topped ripple marks. At the time the picture was taken, water was present between, but not over, the ripple marks. The ruler is approximately 30 cm long. These ripple marks were located by Percival Robertson, at that time visiting professor of geology at Florida State University.

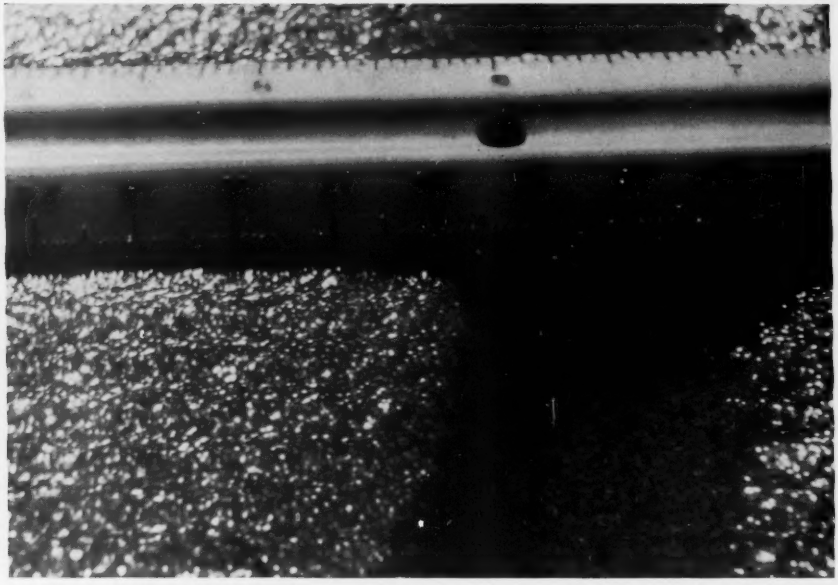

FIG. 2.—Close-up of ruler lying on top of flat-topped ripple marks. The calibrations are in centimeters on the near side, inches on the far side. The shadow of the straight edge indicates the asymmetric shape of the trough between the ripple marks.

coast near Bald Point is not protected by a barrier island. The flat-topped ripple marks were all within 100 yards of the shore line. At the time the pictures were taken, the tide was falling, with about one hour to go to low tide. In water as much as two inches deep, various kinds of flat-topped ripple marks were developed. These included:

1. Simple, parallel, linear forms (figs. 1, 2).
2. Intersecting (interference) linear forms.
3. Linear forms having flat tops marked by a set of smaller ripple marks which did not parallel the larger set (McKee, 1957, plate 7-C).

The simple, linear flat-topped ripple marks had an average wave length of 105 mm, and present amplitude of 18 mm. The Wewoka Formation ripple marks had an average wave length of 70 mm and amplitude of 10 mm. Flat-topped ripple marks were observed, in sandstones, with wave-lengths as great as 220 mm.

It is concluded that very small ripples or wave-lets, moving across a slowly falling water surface, planed the ripple mark crests. This conclusion suggests that the flat-topped ripple marks found in Oklahoma had been exposed to the air prior to cementation.

REFERENCE

McKEE, EDWIN D., 1957, Primary structures in some recent sediments: Am. Assoc. Petroleum Geologists Bull., v. 41, p. 1704–1747.

JOURNAL OF SEDIMENTARY PETROLOGY, VOL. 28, NO. 1, PP. 97–101
FIGS. 1–5, MARCH, 1958

TWO UNDESCRIBED STRUCTURES IN A GREYWACKE SERIES[1]

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ABSTRACT

Two structures in a greywacke series are described, one, termed auto-injection, being considered to be formed by early tectonic pressures on unconsolidated sediments, the other, double banding, being an original feature due to turbidity currents coming from two distinct areas.

The Lower Silurian rocks around Aberystwyth, Wales, belong to a greywacke series locally termed the Aberystwyth Grit Series. Its outcrop runs from south of New Quay to just south of Borth, a distance of some 25 miles. Observations made by Rich (1950), Kuenen (1953) and the authors show that the transporting currents came from the southwest or south-southwest, and confirm an earlier suggestion by O. T. Jones (1912) that the greywacke facies started earlier around New Quay. All the usual features of a greywacke series occur; in the present paper two apparently novel features are described.

1.—*Auto-injection* (figs. 1, 2, 3). Occasionally thin light coloured bands occur within a greywacke bed, and in places may show a double curvature reminiscent of current bedding. Sometimes observation of the apparent truncations may suggest that the beds are upside down. Closer observation shows that the light bands are planar sheets, as can be seen in figure 1, and that they run semiparallel for several inches through the rock. Occasionally branching occurs; one set of sheets may break up into two or three separate sets when traced along the rock face (fig. 2). The sheets do not reach the base of the bed. In one case the base of the containing bed is well graded, the larger grains at the base measuring 1–1.5 mm in diameter, becoming reduced in 9 in vertically to 0.2–0.35 mm with a considerable quantity of dark interstital material. Within the banded portion itself, microscopic observation shows that the light-coloured sheets have less matrix and include larger grains of quartz and felspar than the dark portions. In the dark portions there is sometimes a tendency toward orientation of the darker clay minerals parallel to the walls, which may go so far as to become an incipient cleavage. The light sheets are nearly at right angles to the bedding; their strike is nearly parallel to the strike and to the strike of the cleavage. The cleavage dip lies between the dip of the beds and that of the structures but does not exactly intersect it. Finally, for completeness, it should be mentioned that groove casts on the base of associated beds are nearly parallel to the strike of all these structures.

It is thought that these greywacke beds originally consisted of alternating layers of slightly different grain size, pore space, and water content. It is believed that early tectonic movements, or earthquakes which were the forerunners of these, disturbed the packing of the grains and caused injection of the coarser and more water laden layers into the finer less mobile ones, the grain size relationships and water content being such that the arrangement was stable after injection. The separation of the sheets, and their parallelism to the tectonic trend, is believed to indicate that the beds were already under some compression by tectonic forces when the injection occurred. It may well be that many beds have suffered this processs of auto-injection, indeed this theory would demand it, but the injected material was diffused among the general matrix of the bed. This conclusion is supported by the existence of beds with wisps of coarser grained material, such as the upper bed in figure 3. The preservation of clearly defined parallel sheets would seem to be a rare phenomenon. We have seen only these two instances and one occurrence in a boulder of the Lower Cambrian Hells Mouth Grits of Caernarvonshire.

The use of the term auto-injection is quite analogous to that of auto-intrusion in a magma; in both cases the originating force lies outside the rock itself.

[1] Manuscript received November 14, 1957.

FIG. 1.—Light and dark layers due to auto-injection in greywacke. South end of Aberarth section, south of Aberystwyth, Wales.

2.—*Double Banding* (figs. 4, 5). The beds at Borth, below the local development of the Aberystwyth Grit Facies, but at a level which is probably equivalent to some of the grits in the south, are predominantly mudstones—unbedded and unlaminated. They are probably the product of continuous sedimentation in rather deep water.

Within these beds a peculiar double banding is seen, with an irregular but rather wide spacing, as shown in the figures 4 and 5. The coarsest material is in the centre of the dou-

FIG. 2.—Detail of figure 2, to show separation of light portions into distinct sets, possibly due to ripple drift bedding in original sediment.

FIG. 3.—Vertical marks due to auto-injection in lower bed, traces of auto-injection in bed above. North end of Aberarth section, south of Aberystwyth, Wales.

ble band, and it is often difficult to determine the order of succession from one pair alone. (In figures 4 and 5 the top of the beds is towards the top of the page.) This double banding, occurring at spaced intervals through several hundred feet of beds, is characteristic of this local sequence. The two parts have constantly different properties. The upper one is coarser in grain, often, but not always, graded, often laminated, and sometimes shows small scale current bedding. In these features it resembles the

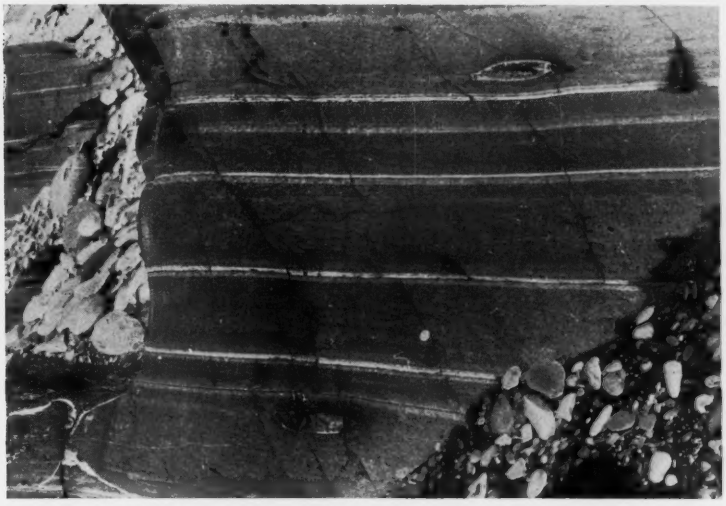

FIG. 4.—Double banding in Borth Beds. Reversal of usual arrangement in topmost double band. Borth, north of Aberystwyth, Wales.

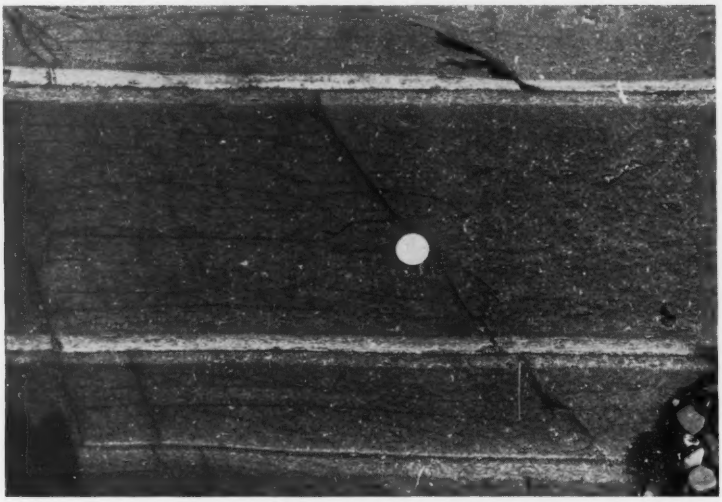

FIG. 5.—Detail of figure 4, to show character of bands more clearly. Lowest double band shows dark layer between the two parts.

thinner and finer grained greywacke beds in the Aberystwyth Grits proper. The base of this upper band is sharp, sometimes welded to the band below, sometimes separated from it by a distinct crack or bedding plane. The lower band is always unlaminated, usually ungraded, with a well-defined, but not razor-edge-sharp base. In those places where this band is graded a darker portion appears below the abrupt base of the band above. In one case reversed grading appears to occur. Sometimes bands of similar character may occur alone within the mudstone and not overlain by a laminated greywacke. Sometimes also one of the thin greywackes may occur without an unlaminated band below, and even more rarely it may have a band above and below, or above only. It is particularly noticeable that the lower bands have the same general spacing as the thin greywackes. The thickness of these bands varies from $\frac{3}{8}$ to $1\frac{1}{2}$ in and is not related to that of the greywacke above. Similarly, the thickness of the lower and upper bands is not related to the thickness of the mudstone above or below, nor to that of the preceding or succeeding bands. Laterally the bands retain their characters as far as they can be traced, usually only about 20 yards.

Various theories have been considered in an attempt to account for the double banding. The presence of casts of worm tracks on the bottom of the thin laminated upper portions and the observation (in higher beds of slightly different lithology) of circular cross sections of tubes infilled with light coloured sediment on the surface of a shale immediately below a greywacke, led to the theory that the lower band might be that portion of the underlying mudstone turned over by worms. In this case the light colour would be due to admixture of light coloured sediment from the greywacke above. The definite lower limit to the band might reflect the depth to which the particular species could penetrate, its sharpness being accentuated by strong compaction. Unfortunately it would seem on this theory that the lower band should always show reversed grading, since presumably the worms would reach the bottom of the band. The grading seen in some bands, and the occurrence of identical bands without an overlying greywacke, seems to rule out this organic hypothesis.

The second theory depends on the observation made by several workers on modern sediments that bacterial action rapidly reduces the amount of available oxygen so that a few centimetres below the surface reducing conditions prevail (Trask, 1939, p.

260, 266, 418, 444). If this were the case in the Borth Beds, and a thin oxidized upper layer were progressively to migrate upwards as sedimentation of the mudstone proceeded, an unusual event, such as the transport of the material forming the laminated greywacke into the area by a turbidity current, might seal off the oxidized surface layer, preserving it to our view as a band of different colour from the already reduced mudstone below. The presence of isolated bands, and the grading sometimes observed in the lower bands, seem to make this theory untenable also.

For similar reasons a third theory, that the lower band was caused by the shaking of the surface layer by an earthquake shock causing its state of aggregation to be disturbed and therefore causing a difference of colour on diagenesis, has had to be abandoned, though the common occurrence below greywackes could have had a connection with the shock which brought turbidity currents into the region.

The only suggestion that fits the observed facts seems to be that the lower bands are themselves deposits from turbidity currents. Such a theory would account for their occasional upward grading, for their spacing, and for the definiteness of the base. Unusual conditions would be required to account for the two types of turbidity current in one region. We have elsewhere shown that a muddy (slurried) bed often underlies greywackes in the southern part of the outcrop of the Aberystwyth Grits; twelve or fifteen miles further north, however, further away from the source area, the greywackes constantly underlie the slurried bed. This was explained by assuming that the material of both beds was started in motion by a single shock. The muddy material came from lower down the continental slope than the coarser, and was deposited first if deposition was rapid. When, however, the currents travelled considerable distances the coarser material overtook the fine clouds, passed them, and hence now underlies their deposits. In the present area the arrangement is reversed again, even though the area was still further from the land in the south. The facts would seem to demand a muddy shoal near at hand and a source of fine grained sand much farther away. When a shock occurred mud reached this area quickly; the silty sand, having farther to travel, arrived much later. The occasional occurrence of light bands isolated in the mudstone may be a record of shocks which were not severe enough to bring sediment from distant regions.

Such a theory accounts for the variation in thickness in the bands and their independence of each others' variation, for the original shock, which shook the sediment free, might be located at varying distances from the two source areas.

REFERENCES

JONES, O. T., 1912, Geological structure of central Wales: Geol. Soc. London Quart. Jour., v. 68, p. 328–344.

KUENEN, PH. H., 1953, Graded bedding, with observations on Lower Palaeozoic rocks of Britain: Verh. Kon. Ned. Akad. Wetensch., Amsterdam, Afd. Nat., 1ste reeks, v. 20, no. 3, p. 1–47.

RICH, J. L., 1950, Flow markings, groovings, and intrastratal crumplings as criteria for recognition of slope deposits, with illustrations from Silurian rocks of Wales: Am. Assoc. Petroleum Geologists Bull., v. 34, p. 717–741.

TRASK, P. D., (ed.) (1939), Recent marine sediments, a symposium: Am. Assoc. Petroleum Geologists, Tulsa, 736 p.

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MARCH, 1958

RULES AND SUGGESTIONS FOR PREPARATION OF MANUSCRIPTS FOR THE *JOURNAL OF SEDIMENTARY PETROLOGY*

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ABSTRACT

An abstract is required for all papers published in the *Journal of Sedimentary Petrology* except short notes which are placed in a section entitled "NOTES" and exclusive of discussions. The abstract should be a condensation and concentration of the essential parts of the paper, not a mere recital of the subjects covered, replete with phrases such as "is discussed" and "is described." The abstracts from the *Journal of Sedimentary Petrology* and other journals are published by the Geological Society of America in a quarterly, *Geological Abstracts*, on behalf of the American Geological Institute and its member societies. In view of this fact, it should be obvious that every abstract should be truly informative. For further discussion of the subject of abstracts, the reader is referred to Landes (1951).

The present abstract was written to define the requirements of abstracts. It is not informative of the other essential parts of this paper.

INTRODUCTION

The rules and suggestions set forth below are published with the hope that many common editorial revisions which have been required on articles submitted in the past for publication in the *Journal of Sedimentary Petrology* can be eliminated before the article is submitted to the editor.

If the advice offered in succeeding portions of this paper is followed, many of the problems encountered regularly in preparing a manuscript to be sent to the printer will be eliminated.

Many of the rules and suggestions which are discussed in one section of this paper are illustrated in another section since this paper is written in a format suitable for technical papers published in the *Journal of Sedimentary Petrology*.

TITLE AND AUTHORSHIP

Titles of papers should be as brief as possible but long enough to be informative. A title is seldom improved by starting with "a," "an" or "the." If the paper is one concerned with regional geology, it is desirable to put the locality of the study in the title. If the paper has to do with rocks of a particular age, it is desirable to include the age of the rocks in the title. For instance, the title, "Authigenic brookite in Cretaceous Gallup Sandstone, Gallup, New Mexico," (Sun and Allen, 1957, p. 265) is more informative than if the location and age had been omitted. No punctuation is necessary at the end of the title.

The author's name is capitalized and is written in the manner indicated by the author of the paper. However, when a paper is referred to in references or in the index, only the author's last name and initials are used. Following the author's name, the professional affiliation and address of the author are listed. Because of space limitations, the full street addresses or post office box numbers are generally not printed; only the general address is used. For example, the address of the authors of this paper is given as "University of Illinois, Urbana, Illinois," rather than "234 Natural History Building, University of Illinois, Urbana, Illinois."

TEXT

All manuscripts submitted for publication in the *Journal* should be typewritten on one side only of $8\frac{1}{2} \times 11$ inch white bond paper. Carbon copies of papers will not be accepted; neither will original copies typed on onion skin paper be considered. Authors should leave wide enough margins on their typed manuscripts for any editorial notes or corrections which may be necessary. The typewritten lines should not exceed 6 inches in length.

All typed material should be double spaced. This includes footnotes, quoted matter, and references. These materials are

[1] Editor.
[2] Editor's assistant.

almost always more difficult to set and to proofread than straight text and there is no point in making them more difficult by single spacing.

If a correction is made in the typed copy, write it in at the same level as the line in which it is to appear. Only brief inserts of a word or two should be attempted in the margin. When longer additions are made the sheet should be cut and the insert pasted in its proper place. Inserts should not be made by fastening narrow overlay strips to the margins of the pages.

The author should retain an exact copy of the manuscript so that minor changes may be discussed in correspondence without transmittal of the manuscript.

Headings

The *Journal of Sedimentary Petrology* does not print an outline or table of contents with each article. The relative importance of the various topics should be indicated by the author in the headings over the various sections of the paper.

First order.—First order headings are printed in all capital letters and are centered in the column. (See "TEXT" above.)

Second order.—Second order headings are printed in upper and lower case letters with the first letter of all words except articles and conjunctions capitalized. Second order headings, like first order headings, are centered in the column. (See "Headings" above.)

Third order.—Third order headings are printed in italics, the first word capitalized, and the heading followed by a period and a dash. (See "*First order, Second order, Third order*" above.) In the manuscript, italics are indicated by a single underline.

As a general rule, first order headings are followed by second order headings and second order headings are followed by third order headings. However, if only a very small amount of description follows a first order heading, the second order heading can be omitted and the third order heading used after a first order heading.

Footnotes and References in Text

Footnotes should be used only when the information included in them cannot be more satisfactorily expressed in the text. Exceptions are the footnotes which indicate date of receipt of the manuscript at the editorial offices of the *Journal*, the footnote which states that the article is published with permission of a company or institution or is a contribution of an institution, and the footnote which may be used to give the author's present address if he has changed affiliation or location after submitting the article for publication. Footnotes are *always* numbered consecutively throughout an article.

Footnotes should be typed on separate sheets or at the bottom of the page. They should never be run into the text.

References in the text are made in the following ways. The author's name, date of publication, and page number can be incorporated in a phrase or the parts of the reference can be inserted parenthetically. Examples of the above are: "Evaporite-reef relationships were discussed by Sloss in 1953, page 154." "Sloss (1953, p. 154) discussed evaporite-reef relationships." "Evaporite-reef relationships (Sloss, 1953, p. 154). . . ." A specific page reference should be given whenever possible, especially in referring to a long paper, bulletin, monograph, or book.

All citations made in the text of an article must be supplemented by a complete reference in the list of references at the end of the paper.

MISCELLANEOUS RULES OF STYLE

In general authors should refer to "Suggestions to Authors" (Wood and Lane, 1935) for suggestions on capitalization, abbreviation, hyphenation, punctuation, and other problems with word usage and style. Listed below are miscellaneous items which commonly are misused in articles submitted for publication in the *Journal of Sedimentary Petrology*. The authors realize that in several cases there is more than one form of expression which is acceptable and correct, but the following may be considered items of style which should be kept consistent in articles printed in the *Journal*.

"X-ray" is always printed with a capital "X" followed by a hyphen and a lower case "r."

"Percent" is usually spelled out as one word in the text. Only if "percent" appears many times in a paper or many times in a small portion of the paper is the percent

sign (%) acceptable in the text. The percent sign (%) is preferable in tables.

No periods are used after abbreviations of units of measurement unless the unit of measurement comes at the end of a sentence. (mm, cm, lb, in, ft, for example).

Names of states, provinces, or countries should not be abbreviated anywhere in the title, text, or references to the article.

The *Journal* has adopted the suggestion of the American Commission on Stratigraphic Nomenclature regarding the capitalization of stratigraphic names. R. C. Moore (personal communication, 1957)[3] states that the "procedure recommended is to use an initial capital letter for all words required in designation of a stratigraphic unit, of whatever rank, and whether rock-stratigraphic or time-stratigraphic." According to this rule, "formation," "member," and other terms which traditionally have not been capitalized when used in connection with stratigraphic names must be capitalized.

All numbers, including 1 through 10, are generally printed as figures in the text when they are used to express a measured quantity unless the number comes at the beginning of a sentence. For example, "The size of the particle was 9 mm long and 3 mm high." "Sixteen traverses were made on each slide" but "In the study 16 traverses were made on each slide." "There are three possible interpretations:"

No comma is needed in four digit numbers. That is, the figures 1000 through 9999 are written without a comma.

In writing a series of items, lithologies, locations, or some other series, there is always a comma used before the conjunction which precedes the last item of the series.

Latin usage should be avoided wherever possible. Avoid the Latin phrases and abbreviations such as "*in situ, i.e., e.g., et al.*" by using "in place, that is, for example, and others." "*Etc.*" is frequently misused and over-used by many authors. Avoid its use whenever possible.

For details of usage not mentioned here, the reader is referred to recent issues of the *Journal of Sedimentary Petrology* for examples.

The less experienced writers will profit from a study of Suggestions to Authors (Wood and Lane, 1935).

[3] Personal communication can be cited in the text as illustrated above or in a footnote, without any additional citation appearing in the list of references.

ILLUSTRATIONS

Illustrations form an important part of most papers, and much information can be conveyed by illustrations that cannot be as effectively brought out in the text. With this in mind, the *Journal* encourages the use of as many illustrations as can be used to advantage in an author's presentation. However, there is often a tendency for an author to use too many figures to illustrate the same point; for instance, 3 photographs of a sedimentary feature might be submitted when one good photograph would be sufficient.

All illustrations should be called figures. Some illustrations have been designated as plates in the past, but it is more desirable in most cases to separate the individual figures and number them consecutively in the text.

The figures should be numbered in the order in which they are cited in the text. Each figure that is included in an article *must* be referred to in the text of the article.

Copy for most illustrations is submitted larger than it will appear in print. Therefore, when providing a scale on maps or enlargements on photographs or photomicrographs, authors should be sure to consider the reduction in size. For instance, if a scale is stated as 1 inch equals 1 mile, the scale will be inaccurate when the map is reduced. Graphic scales are preferable. Indexes of magnification, such as "180×" will be recalculated by the editor if the size of the illustration is changed. Photographs should be cropped so that the picture of the item to be illustrated captures the reader's attention at first glance and is not lost in extraneous background material. Glossy prints of all photographs should be submitted.

Maximum size for reduced figures is generally type page size ($5\frac{1}{8} \times 7\frac{3}{8}$ in). Occasionally a fold-in illustration or table is used, but fold-ins are expensive and bulky, and therefore they are seldom used.

All maps, line drawings, and diagrams should be prepared with India ink on white drawing paper or on tracing cloth.

In the preparation of maps, graphs, and other line drawings, authors could help greatly if they drew their original figures exactly 3 times the size of the illustration as it will appear in the published article. It should be, therefore, 3 times one *Journal* column width or 3 times one *Journal* type page width, or 3 times one type page length minus the space required for the printed caption to appear below the illustration.

No symbol, letter, or figure on the published illustration should be less than 1 mm. in size. Many illustrations could be reduced to single column width if the symbols were large enough on the original copy, thus saving three-fourths of the space taken by a full type-page width illustration. Drawings should be designed to give a compact distribution of material and should not have notations or any other parts extending far outside the areas required for their essential parts. It is desirable to keep to a minimum the amount of material shown in an illustration, so that the main points may be seen more readily.

Because a caption set in type, must appear below a figure, authors should not letter a caption on maps, graphs, and other line drawings. All captions for figures should be typed on manuscript pages, separate from the illustration copy. "FIG" (all capital letters), followed by a period, a number, a period, and a dash, is used for the figure captions. Arabic numerals are always used for figures. For example, a caption under the first illustration might read: "FIG. 1.— Map showing the location of the Esperanza basin." The illustration copy itself may be identified by placing the figure number only in the margin.

Figures are referred to in the text in one of two ways. If the reference to the figure is part of the sentence (The area of outcrop is shown in figure 1.), "figure" is spelled out and the "f" is written in lower case. If the reference to the figure is made parenthetically (The area of outcrop (fig. 1) . . .), the abbreviation, "fig.", is used inside the parentheses. Once again the "f" is lower case.

Additional information from a publication by Ridgway (1920) may be useful in helping the author prepare illustrations for publication.

In the manuscript, all illustrations should be grouped and placed after the text material. The printers and editors will insert the figures as close to the places where they are cited in the text as spatial limitations allow.

TABLES

Much information which would take many pages of text to explain can be clearly and concisely presented in tables which can be inserted in the text near the places where they are cited.

Table headings are always italicized (underlined in the manuscript), and only the first letter of the first word is capitalized unless some word which is normally capitalized appears in the heading. No punctuation is required at the end of a table heading.

Tables are always numbered with arabic numerals.

Tables may be set in type and need not be drafted by the author.

All tables used must be referred to in the text. When tables are referred to in the text, the "t" of the word "table" is never capitalized unless "table" is the first word of the sentence.

Unnumbered tabulations, unless they are very brief and contain less than 42 characters and spaces per line, may not be used. In general tabulated material should be set up as a numbered table.

In the manuscript, all tables should be grouped and placed after the text material. The printers and editors will insert the tables as close to the places where they are cited as spatial limitation allows.

REFERENCES

Only articles and books referred to in the text of the manuscript should be listed in the list of references which is printed at the end of the paper. Note that the correct title of this section is "REFERENCES," not "List of References" or "Bibliography."

Each reference to an article which appears in the *Journal* should include the following information:

Author's name (written in capital letters), date of publication, title of article (followed by a colon), name of journal, volume, number (if necessary), and pages.

An example of the above style of reference follows:

KRUMBEIN, W. C., 1934, Size frequency distribution of sediments: Jour. Sedimentary Petrology, v. 4, p. 65–77.

Note that only the first word of the title of the article is capitalized unless succeeding words are place names, formation names, or other words which normally require capitalization.

Neither quotation marks nor underlining is used with the titles of journal articles or books.

Abbreviations of the names of specific journals are taken from pages 22–29 of Wood and Lane, 1935. The abbreviations of the journals which contain articles most frequently cited in the *Journal of Sedimentary Petrology* include:

Am. Assoc. Petroleum Geologists Bull.
Am. Jour. Sci.
Am. Mineralogist
Geol. Soc. America Bull.
Geol. Soc. London Quart. Jour.
Illinois Geol. Survey Bull. (never abbreviate state names in references)
Jour. Geology
Jour. Paleontology
Jour. Sedimentary Petrology
U. S. Geol. Survey Memoir
U. S. Geol. Survey Prof. Paper

Since most journals number their pages consecutively throughout an entire volume, it is usually unnecessary to list the number in which a paper appears since this information can be ascertained by looking at the page number of the article.

If an abstract of an article is listed in the References, indicate that the reference is an abstract by inserting (abs.) after the title of the paper.

Each reference to a book should include the following information:

Author's name (written in capital letters), date of publication, title of book (followed by a period), edition, publisher, city where published, state (if necessary), number of pages in the book.

An example of the above style of reference follows:

PETTIJOHN, F. J., 1957, Sedimentary rocks. 2nd ed., Harper and Brothers, New York, 718 p.

The same rule applies to books that applies to journal articles concerning the punctuation in the references.

Note that the publisher's name is spelled out (for example, Harper and Brothers, not Harpers). The location of the state in which the publisher is located is unnecessary if the location of the city leaves no doubt about where the book is published (for example, London, Boston, Philadelphia, Paris).

The number of pages in the entire book is listed in the reference, not just the parts of the book referred to in the text. If the author wishes to call attention to more specific parts of the book in the text, for instance to the section on lithification and diagenesis in Pettijohn's *Sedimentary Rocks*, he can do so by writing (Pettijohn, 1957, p. 648–681) in the text.

References should be arranged in alphabetical order of authors' names, with items by the same author listed in chronological order. If two items by one author bear the same date, one is identified by a lower case "a" following the date (for example, 1958a) and the other is identified by a "b" following the date. These designations are used in both the text and the list of references.

If two or more items by the same author appear in the list of references, the author's name appears only with the first item. In subsequent references a line is used in place of the author's name. However, if a paper follows in which there is more than one author, the full name of both authors is given.

Additional details of citation may be observed in the list of references at the end of this article.

CORRECTION OF GALLEY PROOF

The printers of the *Journal*, the George Banta Company of Menasha, Wisconsin, send galley proof to the author for correction. The printers proofread the galley and the editor will also proofread it, but it is primarily the responsibility of the author to eliminate errors. Careful reading is necessary, particularly of tables and mathematical formulae. The cost of alteration of text material will be minimized if, wherever possible, the substitutions are equal in number of letters to corresponding deletions. If it is necessary to insert new material, it should

be added at ends of paragraphs and preferably as new paragraphs. Only reasonable corrections, not radical alterations, can be made in the galley proof.

REPRINT ORDERS

Each author will receive a reprint order blank from the printer at the time he receives galley proof of his paper. This reprint order blank must be filled out and sent to the editor along with the corrected galley of the paper. No reprint orders can be filled after the paper appears in print because the printer destroys the type shortly after the press-run.

ACKNOWLEDGEMENTS

If any acknowledgements are to be included in a paper they should appear as the last section of the paper before the references.

The authors of the present paper acknowledge assistance given by the following persons who read the manuscript and made helpful suggestions: Ralph E. Grim, William C. Krumbein, Raymond C. Moore, Francis J. Pettijohn, Gordon Rittenhouse, and Robert R. Shrock.

REFERENCES

KRUMBEIN, W. C., 1934, Size frequency distribution of sediments: Jour. Sedimentary Petrology, v. 4, p. 65–77.

LANDES, K. K., 1951, A scrutiny of the abstract: Am. Assoc. Petroleum Geologists Bull., v. 35, p. 1660.

PETTIJOHN, F. J., 1957, Sedimentary rocks. 2nd ed., Harper and Brothers, New York, 718 p.

RIDGWAY, J. L., 1920, The preparation of illustrations for reports of the United States Geological Survey: U. S. Geol. Survey, 101 p.

SLOSS, L. L., 1953, The significance of evaporites: Jour. Sedimentary Petrology, v. 23, p. 143–161.

SUN, MING-SHAN, AND ALLEN, J. E., 1957, Authigenic brookite in Cretaceous Gallup Sandstone, Gallup, New Mexico: Jour. Sedimentary Petrology, v. 27, p. 265–270.

WOOD, G. M., AND LANE, B. H., 1935, Suggestions to authors of papers submitted for publication by the United States Geological Survey: U. S. Geol. Survey, 4th ed., 126 p.

JOURNAL OF SEDIMENTARY PETROLOGY, VOL. 28, NO. 1, PP. 108–110
FIGS. 1–2, MARCH, 1958

NOTE

NEW TECHNIQUE FOR MEASURING ROUNDNESS OF SAND GRAINS

D. A. ROBSON[1]
King's College, Durham University, Newcastle-upon-Tyne, England

The definition of the term "roundness" was considered by Wadell in a paper in 1932, where he discussed the distinction between "shape" and "roundness." In a later paper (Wadell, 1935) he described a method of actually measuring roundness of grains. The process is laborious, since the outline of each grain has to be reproduced as a camera lucida drawing, and the radii of curvature measured by placing over the drawing a celluloid grid consisting of concentric circles of known radii. The coefficient of roundness of each grain is then determined from the expression

$$\frac{r_1 + r_2 + r_3 \cdots}{RN}$$

where r_1, r_2, r_3, etc. are the radii of curvature of the corners, R the radius of the inscribed circle, and N the number of corners measured.

Though this made possible a measured classification of roundness, the practical drawbacks of this method are so great that workers generally prefer a visual classification, such as that devised by Russell and Taylor (1937) and by Powers (1953). Nevertheless, it is clearly preferable to classify grains on a measured basis, so as to be able to represent the results in graphical form.

While working on the Carboniferous sediments of Northumberland, England, the writer (Robson, 1956) realized the need for a reliable but rapid method of estimating roundness in large numbers of grains. Visual observation suggests for example, that the detrital apatites in the Old Red Sandstone are more rounded than those of similar size in the overlying Cementstones. If this could be confirmed by counts carried out on a rigorous statistical basis, both for apatites and other minerals unaffected by post-depositional solution or regrowth, the results might be of value in identifying the source rocks of a sandy formation.

A special graticule has therefore been contructed which can be inserted in the slit ocular of a microscope. Figure 1 shows some details of the construction of the graticule holder, and the manner in which it is operated when placed in the ocular of a Swift microscope. Movement is achieved by means of a brass thimble operating a simple friction drive set in the framework of the microscope. The graticule consists of a series of circles numbered 1 to 20 and 22 to 50 (fig. 2). The numbers accompanying the circles are directly proportional to their diameters and may be used directly in the expression for the coefficient of roundness, whatever the magnification of the objective. The circles are arranged in two lines parallel to the length of the graticule, so that each circle can be brought into position close to the center of the field of view.

The minerals to be measured are separated in an electromagnetic separator, and spread out dry on a counting slide. This is a 3×1-inch slide with a ground glass surface, having a grid marked on it with a fine hard pencil. A convenient size for the grid is a 1-inch square, divided into one hundred squares. If too many grains of the selected species are present on the slide, random samples may be chosen under a binocular microscope from widely scattered squares, and arranged together on some empty part of the slide. All grains of the particular species should be included from each square selected. The slide is then transferred to the monocular microscope, with graticule inserted. The microscope is fitted with a mechanical stage, set so that it traverses parallel and at right angles to the length of the graticule. The slide is tapped gently before fixing in the stage so that the grains come to rest in stable equilibrium. Measurements are then carried out and the results combined in either of the formulae recommended by Wadell. Using transmitted light, it is possible to measure up to 50 grains per hour by this method.

[1] Manuscript received January 14, 1957.

ACKNOWLEDGEMENTS

The author is grateful to Professor P. Allen of Reading University, England, for comments on the manuscript, to Mr. St. John Lee for his skill in constructing the graticule and to Mr. A. E. Brown (both of the Dept. of Geology, King's College) for adapting the graticule for use in a microscope.

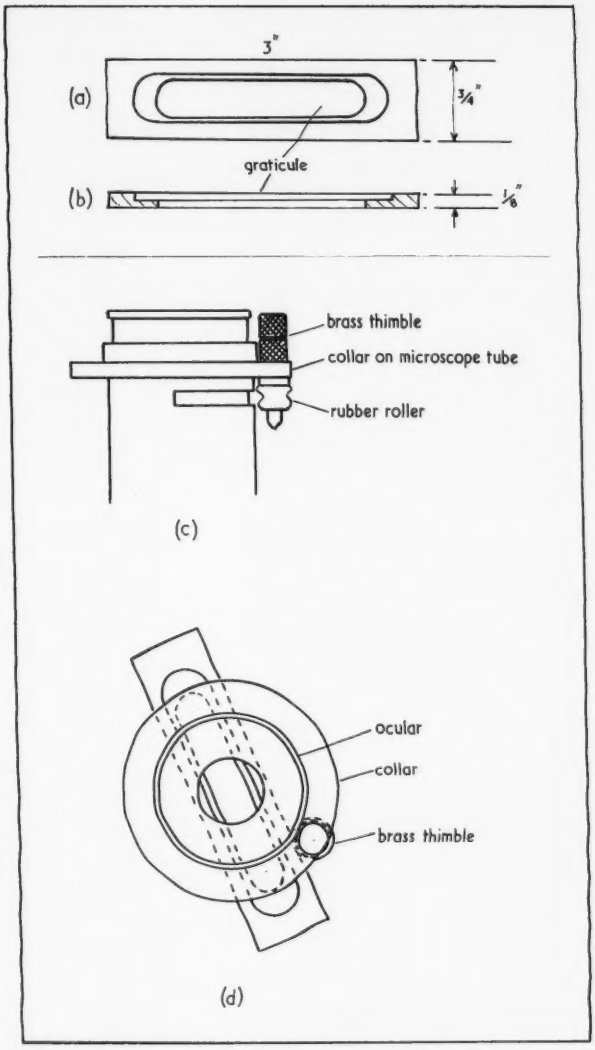

FIG. 1.—(a) Plan view of graticule.
(b) Longitudinal section through graticule.
(c) Vertical view of microscope tube, showing method of operation of graticule.
(d) Plan view showing position of graticule within the ocular.

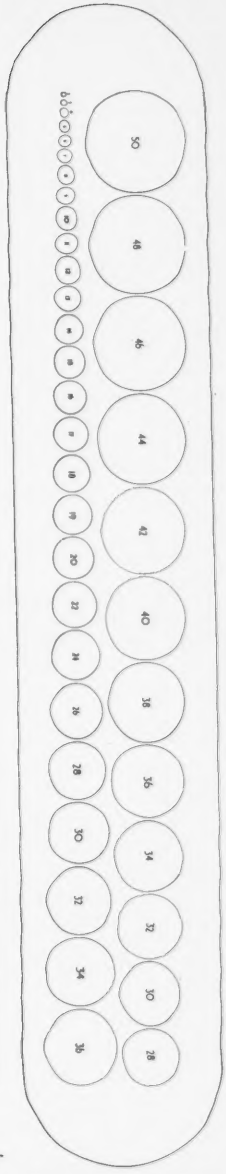

FIG. 2.—The graticule.

REFERENCES

POWERS, M. C., 1953, A new roundness scale for sedimentary particles: Jour. Sedimentary Petrology, v. 23, p. 117–119.

RUSSELL, R. D., AND TAYLOR, R. E., 1937, Roundness and shape of Mississippi River sands: Jour. Geology, v. 45, p. 225–267.

ROBSON, D. A., 1956, A sedimentary study of the Fell Sandstones of the Coquet valley, Northumberland: Geol. Soc. London Quart. Jour., v. 122, p. 241–262.

WADELL, HAKON, 1932, Volume, shape and roundness of rock particles: Jour. Geology, v. 40, p. 443–451.

———, 1935, Volume, shape and roundness of quartz particles: Jour. Geology, v. 43, p. 250–280.

JOURNAL OF SEDIMENTARY PETROLOGY, VOL. 28, NO. 1, P. 111
MARCH, 1958

ERRATA

RELATIONS OF GYPSUM AND ANHYDRITE

LEO OGNIBEN, 1957, Jour. Sedimentary Petrology, v. 27, p. 469–470.

The last paragraph of column 2, page 469, should read: "Goldman (1952) did not find the selenitic type of gypsum in his cap rock, but only superindividuals and fine grained aggregates.

The writer's address has been misinterpreted. It should be written: "A.N.I.C., Via di Villa Trabia 9, Palermo, Italia"; where A.N.I.C. is for "Azienda Nazionale Idrogenazione Combustibili."

ERRATA FOR S.E.P.M. SPECIAL PUBLICATION NO. 5

GEOLOGICAL STUDIES ON THE GREAT BAHAMA BANK

NORMAN D. NEWELL AND J. KEITH RIGBY, 1957, Regional aspects of carbonate deposition, S.E.P.M. Special Publication No. 5, p. 15–72.

In our paper published recently in the SEPM's Special Publication No. 5, "Regional Aspects of Carbonate Deposition," we failed, quite unintentionally, to credit John V. Byrne with the mechanical analyses of sediment samples #69-247 of our text figures 18, 19. The graphic scale of figure 6 is in error. It should read 0, 10, 20 instead of 0, 5, 10 miles.

A STATISTICAL STUDY OF HEAVY MINERALS IN SANDS OF THE SOUTH RIVER, AUGUSTA COUNTY, VIRGINIA

DOROTHY CARROLL, 1957, Jour. Sedimentary Petrology, v. 27, p. 387–404

The following table should be substituted for table 4 in the original article:

TABLE 4.—*Types of zircon in samples of sands from north and south side tributaries of the South River, Augusta County, Virignia (localities given in fig. 1)*

Types	1	2	3	4	5	6
	%*	%	%	%	%	%
North side tributaries—draining Middle Cambrian to Lower Ordovician rocks						
Locality 6	13	1.5	1.7	13.5	40	30
Locality 9	31	.5	1	15	33	19
Locality 10	35	1	1.5	16	30	16
Locality 11	34	2.5	1	18	29	14
Locality 15	29	4.7	2	17	28	17
Average:	29	2	1.5	16	32	19

Types	1	2	3	4	5	6
	%*	%	%	%	%	%
South side tributaries—draining Lower Cambrian and Precambrian (?) rocks						
Locality 6	11	3.7	2.2	6	46	28
Locality 7	24	2.7	2.7	8	35	28
Locality 8	9	2.7	2.7	9	43	32
Locality 12	7	27	3	17	30	14
Locality 13	17	15	2	5	41	18
Average:	14	15	2.6	9	39	24

* Percent by number in zircon population obtained from a count of 100 randomly selected grains.

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MARCH, 1958

ANNOUNCEMENTS

FIFTH INTERNATIONAL CONGRESS OF SEDIMENTOLOGY

The Fifth International Congress of Sedimentology is to be held in Switzerland, at Geneva and Lausanne, from June 2 to 7, 1958 and is organized by Professors A. Lombard and A. Bersier.

Two days and a half will be devoted to formal sessions; field trips are scheduled around Geneva, in High-Savoy, for studies on the Flysch sedimentation and around Lausanne for studies on Molasse sedimentation and recent sediments of Lake Geneva.

A four-day complementary field trip focused on particular problems of Flysch and Molasse is planned after the Congress if enough registration is provided. The deadline for registration is April 1, 1958. For information, write to:

Secretary of the Fifth International Congress of Sedimentology
Geological Museum, Palais de Rumine
Lausanne, Switzerland.

PERMIAN BASIN SECTION FIELD TRIP

The Permian Basin Section of the SEPM announces its 1958 Spring Field Trip—"Cretaceous Platform and Geosyncline, Culberson and Hudspeth Counties, Trans-Pecos Texas." The date of this trip is April 10, 11, and 12, 1958. Registration will be at Van Horn, Texas, on the afternoon of April 10, 1958.

Professor R. K, DeFord of the University of Texas and Dr. John P. Brand of Texas Technological College will be joint leaders of the trip. Localities in the Apache Mountains, Wylie Mountains, Van Horn Mountains, and Indio Mountains will be studied.

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MARCH, 1958

SOCIETY RECORDS AND ACTIVITIES

NEW OFFICERS S.E.P.M.

through March, 1959

President: GORDON RITTENHOUSE, Shell Development Company, Houston, Texas
Past-President: RICHARD V. HOLLINGSWORTH, Paleontological Laboratory, Midland, Texas
Vice-President: W. M. FURNISH, State University of Iowa, Iowa City, Iowa
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Co-Editors, Journal of Paleontology: M. L. THOMPSON AND CHARLES W. COLLINSON, Illinois State Geological Survey, Urbana, Illinois
Editor, Journal of Sedimentary Petrology: JACK L. HOUGH, University of Illinois, Urbana, Illinois

NEW OFFICERS OF PACIFIC SECTION

President: EDWARD L. WINTERER, University of California, Los Angeles, California
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THE SOCIETY OF ECONOMIC PALEONTOLOGISTS AND MINERALOGISTS

PROGRAM FOR S.E.P.M., LOS ANGELES MEETING

Stuart A. Levinson, Technical Program Chairman

RESEARCH COMMITTEE SYMPOSIUM: SILICA IN SEDIMENTS

1. INTRODUCTION, H. A. Ireland, University of Kansas, Lawrence, Kansas
2. THE GEOCHEMISTRY OF SILICA IN SEDIMENTARY ENVIRONMENTS, Konrad Krauskopf, Stanford University, Stanford, California
3. THE REMOVAL OF SILICA FROM MISSISSIPPI RIVER WATER AS IT ENTERS THE GULF OF MEXICO, George B. Bien, David E. Contois, and William H. Thomas, Scripps Institution of Oceanography, La Jolla, California
4. BEHAVIOR OF SILICA DURING DIAGENESIS, E. C. Dapples, Northwestern University, Evanston, Illinois
5. PETROLOGY AND GEOCHEMISTRY OF SILICA CEMENTATION IN SOME PENNSYLVANIAN SANDSTONES, Raymond Siever, Harvard University, Cambridge, Massachusetts
6. SILICEOUS ORGANIC REMAINS IN PELAGIC SEDIMENTS, William R. Riedel, Scripps Institution of Oceanography, La Jolla, California
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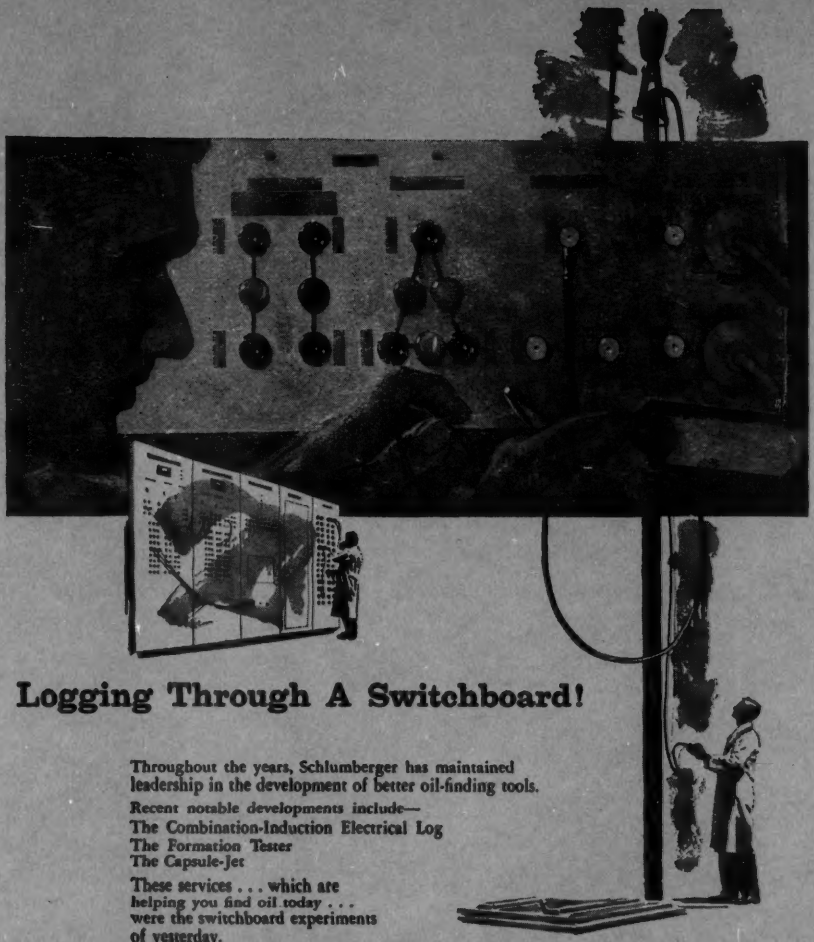

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